Second Biomass Conference of the Americas:

Energy, Environment, Agriculture, and Industry

PROCEEDINGS

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SECOND BIOMASS CONFERENCE OF THE AMERICAS:

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National Renewable Energy Laboratory
Golden, Colorado

PREFACE

The Oral Papers and Poster Papers presented at the Second Biomass Conference of the Americas in Portland, Oregon, August 21–24, 1995, and available when publication of this book was initiated, are reproduced herein. Almost all of these papers were published as received, whether they were in camera-ready form or not. The technical content of each paper and the opinions expressed are attributed entirely to the authors. In a few cases, grammatical and format changes were made and abstract pages were retyped to improve readability.

As in the First Biomass Conference of the Americas held in Burlington, Vermont, in 1993, the Second Biomass Conference of the Americas was designed to provide a national and international forum to support the development of a viable biomass industry. Papers on research activities and technologies under development that address industry problems were included in the program, but the main emphasis was on scale-up and demonstration projects, technology transfer to end users, and commercial applications of biomass and wastes. The conference was divided into these subject areas:

- Resource Base
- Power Production
- Transportation Fuels
- Chemicals and Products
- Economic, Financial, and Policy Issues
- Sustainability and Environmental Issues
- European Biomass Energy Developments
- Latin American Biomass Energy Developments

The papers in this book are grouped in the same subject areas.

We believe this conference is unique and that it fills an important need to document and disseminate information on biomass developments in the Americas. The program sponsors plan to present this conference biennially in coordination with the biennial conference presented by the European Commission on biomass developments in Europe. The Third Biomass Conference of the Americas has been scheduled for presentation in Canada in 1997.

We would like to express our sincere appreciation to all the authors, who made an extra effort to produce quality papers under a very rigid time schedule, to the Session Chairs who also doubled as members of the Program Committee and assisted in the selection of papers, to the Conference Organizing Committee, the Scientific Advisory Committee, and the Executive Committee, whose members provided valuable guidance and made policy decisions essential to the success of the meeting, and to the conference sponsors—the U.S. Agency for International Development, the U.S. Departments of Agriculture and Energy, the U.S. Environmental Protection Agency, Natural Resources Canada, and the National Renewable Energy Laboratory, under whose auspices the conference was presented. The cooperation of these organizations was the prime ingredient essential to the planning, organization, and presentation of this conference.

Donald L. Klass
Entech International, Inc.

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DEMONSTRATION AND COMMERCIAL PRODUCTION OF BIOMASS FOR ENERGY

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Abstract

Five years ago, environmentally benign biomass crop technologies were only beginning to be commercialized and they were being used for products other than fuels. Twenty organizations could be identified in the U.S. and Canada that had plantings of at least 20 ha in size or greater of short-rotation woody crops and of those 12 were established by forest products companies. All commercial activity was with woody crops since herbaceous crops were still be evaluated by the DOE program. In the intervening 5 years, significant progress has been made on identifying the potential of a herbaceous crop, switchgrass, as an environmentally desirable and highly productive potential energy feedstock. The recent harvest and use of hybrid poplars for pulp and paper production have clearly demonstrated the value of genetically superior hybrid poplar clones. Significant progress has been made in developing sophisticated techniques which will enable even more improvement of hybrid poplars for a variety of locations. Interest is emerging from the forest products industry in all parts of the country regarding the potential of short-rotation woody crops. While the primary use of commercially planted woody crops continues to be for pulp and paper, energy is a co-product in nearly all situations. Additionally, some serious consideration is being given to the economics of using woody and/or herbaceous crops for a variety of energy production processes. Feasibility studies have or are being conducted by 10 or more groups around the country and several serious proposals for biomass energy demonstrations have recently be received by the Department of Energy in response to a solicitation for cost-shared demonstration projects. There continue to be numerous constraints to the commercialization of biomass crops for energy without federal assistance or policy modifications. The success of research and demonstrations over the next 5 years will be key to determining the rate of adoption of biomass energy technologies in the United States.

Introduction

The U.S. Department of Energy initiated biomass energy research in 1978, viewing it as a viable alternative to fossil fuel and has focused on strategies to implement biomass energy if sources of fossil fuels became unavailable. While the fuel shortages foreseen in the 1970's have not materialized, environmental concerns associated with fossil fuel use are increasingly important, the potential for creating jobs in rural areas has been recognized, and the possibility of assisting the farm economy even while reducing farm subsidies is being considered. Consequently the federal government has pursued biomass energy research and is now attempting to bring it to an integrated demonstration phase so that the benefits of biomass energy systems can be fully explored and documented (DOE, 1994). Meanwhile forest products companies have recognized that supplies of wood in some regions of the country are beginning to be limited and that the production of fast-growing trees crops may have economic advantages (Arnold 1995, Am. For. and Paper Ass. 1994). A surge of interest from several forest products companies is resulting in numerous new trials being established for evaluation and the consideration of techniques such as irrigation that have normally been considered too expensive for energy. This paper briefly summarizes the demonstrations and commercial biomass crop activity that is occurring the U.S. and Canada and the barriers that remain relative to using biomass crops for energy. The paper further discusses the implications of these activities relative to the potential for biomass crops to contribute to energy demands in the U.S. in the near future.

Herbaceous Crop Demonstration and Commercialization

The demonstration and commercialization of herbaceous crops for energy is only beginning though many of the candidate crops have been grown for other purposes for 10's to 100's of years. For example, sugarcane has been grown commercially for the production of sugar for decades. The commercial production of this, or similar crops for energy, would be very, if not exactly similar to the methods and technologies currently used. While new varieties selected specifically for high yield might be substituted if the crops are fully dedicated to energy, it is likely that the co-production of sugar and electricity (from the sugarcane bagasse) will continue to be more economically viable in the near future. Annual crops such as rapeseed and soybeans are being used to produce biodiesel, a diesel fuel substitute. Corn grain is being used on a significant scale in the production of ethanol. Alfalfa, a major forage crop, has the potential for use as an energy crop when utilized in a co-product mode with the nutrient rich leafy part of the crop being used as an animal feed and the stems being used as the energy resource. Perennial grasses, the herbaceous crops which appear most likely to be included in a dedicated feedstock supply system (DFSS) for an energy facility are the focus of this article.

Switchgrass, one of many perennial grass species, was selected in 1990 by the Department of Energy's Biofuels Feedstock Development Program as a model species deserving further research and development. This selection was based on the results of screening trials in the Northeast, Southeast, Midwest, and Great Plains regions. Yields in the early screening trials were not particularly high, ranging from 2-14 dry Mg ha^{-1} yr^{-1}, but switchgrass tended to stand out, particularly during the dryer years. A select variety of switchgrass, Alamo, produced as much as 34 dry Mg ha^{-1} in one year in one location. A limited switchgrass breeding effort was initiated for switchgrass in the North Central region in 1990 and a second, more comprehensive breeding and selection program was initiated for switchgrass in the South in 1992. Field trials of available varieties were initiated at three institutions (and 15 locations) in the south in 1992. Third year results from those trials are showing average yields of the best varieties in the range of 15 to 17 dry Mg ha^{-1} and maximum yields of 20 to 27 dry Mg ha^{-1}.

Switchgrass is commercially grown in the sense that it has been planted widely in many part of the U.S. as forage and was one of the several perennial grasses used to satisfy the requirements for lands placed in the Conservation Reserve Program during the past 10 years. For example at least 36,400 ha were planted on CRP land in the green hills area of Missouri and at least 7,200 ha were switchgrass (McLaughlin, ORNL, personal communication). Farmers in Alabama and Texas have planted the select variety, Alamo, on the order of at least a few hundred acres as a forage crop.

Serious consideration of producing switchgrass in a DFSS is being pursued in the Chariton Valley area of Iowa, in Kansas, and in Alabama. Potential energy end-users and potential producers or representatives of producers populations are engaged in developing business plans for the potential production of energy from switchgrass in those locations. In Iowa, the candidate conversion technology is co-firing with coal to produce electricity, in Kansas the candidate technology is fast pyrolysis to produce a biocrude oil and in Alabama, it is a gasification technology serving as a precursor to an ethanol production system. Individuals or groups of other areas of the U.S. such as Wisconsin, Nebraska, and Pennsylvania have expressed interest in the use of switchgrass for energy but it is not known whether the interest has evolved into actual feasibility studies.

Woody Crop Demonstration and Commercialization

The first large scale trials of the SRWC concept actually occurred in the mid to late 70's and early 80's. Several northern pulp and paper companies and other private groups established trials of hybrid poplars on the order of 5 to 200 ha in the North Central and Northeastern portions of the U.S. and in eastern Canada. Several southern pulp and paper companies also began the establishment of several thousand hectares of sweetgum, sycamore and cottonwoods during the same time period (Wright 1990). Many of these plantings either failed or are not currently categorized as short-rotation since the appropriate rotation ages are estimated to be between 15 and 20 years of age. Most of the early failures were due to a combination of poor site selection, disease problems, inadequate silvicultural methods and growth rates which did not match expectations. These failures certainly contributed to a loss of private interest in SRWC at the time that the DOE Short Rotation Woody Crops Program and the Ontario Ministry of Natural Resources Fast Growing Forest Program were just beginning.

Both the Canadian and U.S. research programs on short-rotation woody crops addressed the issues and problems identified by the early plantings. The Ontario program addressed the problems by working directly with an interested industry, Domtar, and learned by doing as they assisted Domtar in managing plantations on Domtar lands. Some of the early hybrid poplar plantings have been replaced with other species. Domtar has continued to be involved with hybrid poplars but they have leased higher quality land from farmers close to the mill and have improved their planting and management techniques (Adam Zulinski, Domtar, personal communication, May 1995). The U.S. program addressed the issues associated with SRWC by funding a variety of projects, primarily with academic institutions or the U.S. Forest Service, at several different locations around the country. The most successful of these projects gradually developed collaborative activities with industry as the value of their work became apparent. Most of the private sector plantings of SRWC which occurred between 1980 and 1994 have been closely linked with a university SRWC research program funded by DOE.

Recent interest by the private sector in SRWC has increased noticeably just within the past 2 years. Table 1 summarizes the status of active SRWC projects in the U.S. and Canada and the amount of land involved. Of particular interest is the column identifying new activity since my last assessment in 1990 (11 of the 12 new planting starts have actually occurred in 1994 or 1995). Most new plantings have been initiated by pulp and paper industries, however some of the projects under evaluation include feasibility studies being done for the purposes of producing biomass energy. Pulp and paper company interest is being stimulated, in part, by the current or anticipated reduction in hardwood supplies that is resulting from environmentally driven legislation and regulations in the U.S. Forest products industry interest is also being driven by the recognition of the worldwide competitive advantages being gained by the production of fast growing hardwoods in places like Brazil, Chili, South Africa, and Indonesia. If higher quality, lower cost fiber supplies can not be established in the U.S. then many jobs in the forest products industry will be lost or moved overseas.

Table 1. Summary of Short Rotation Woody Crop Demonstration and Commercialization Activity in the U.S. and Canada.

1995 ha (ac) Managed	2000 ha (ac) Planned	Commercial Projects	R & D Scale-up Projects[1]	Entities evaluating projects	Total (new)[2]	New or Larger Nurseries
PACIFIC (California, Oregon, Washington, British Columbia)[3]						
20,000 (50,000)	47,000 (115,000)	7	1	3	11 (3)	6-8 known
SOUTHERN U.S.[4]						
12,000 (30,000)	27,500+ (68,000+)	4	6	3	13 (3)	1 known
NORTH CENTRAL & NORTHEAST U.S., CENTRAL AND EASTERN CANADA[5]						
3,800 (9,500)	4,900++ (12,200++)	1	7	2	10 (5)	6-8 known
HAWAII[6]						
290 (725)	10,000 (25,000)	0	1	1	2 (1)	unknown

1. Plantings are either less than 500 acres or the market has not been specifically identified.

2. Total includes projects under evaluation but new category includes only projects planting crops since 1990.

3. Pacific commercial SRWC projects (with planting initiation years) include: James River Corp (1982), Scott Paper Ltd. (1984), Simpson Timber (1986), MacMillan Bloedel (1988), Boise Cascade (1991), Potlatch (1994), Georgia Pacific (1995), Ag West, (1995). Lousiana Pacific Corp. in CA with about 120 ha considered R&D Alberta Pacific, Fletcher Challenge, and Weyerhaeuser Corp. are evaluating or planning projects.

4. Southern U.S. commercial SRWC projects (with planting initiation years) include: James River Corp. (1982), Westvaco Corp. (1984), Scott Paper Co. (1988), Union Camp, (1995). The 23,000 acres of 15-20 year rotation Sweetgum managed by Union Camp and Westvaco are not included. Projects put in the R&D category include: Federal Paper Board (1987), municipal wastewater projects of Edenton & Woodland, N.C., Champion Paper Co. and an energy company in Florida. Entities evaluating or planning SRWC plantings include Natural Resource Holdings, John Sutherland, and a group in Kansas.

5. The only active commercial project in the central and eastern part of the U.S. or Canada is the one maintained by Domtar, a pulp and paper company in Ontario which was initiated in 1974. Other early projects totalling 400-800 ha have been abandoned or their status is unknown. Projects in the R&D phase are several including: State University of New York & University of Toronto trials of willow in New York and Ontario; US DOE co-sponsored clone sites trials in Minnesota & Wisconsin, US DOE co-sponsored scale-ups near Alexandria, Minnesota; Minnesota State & Minnesota Power scale-ups near Oakly, Minnesota; trials by Champion Paper , Georgia Pacific, & Energy Performance Systems. Blandin Paper Co and Potlatch are in the planning/evaluating phase in Minnesota. Year 2000 land area planted will likely be much larger than indicated if both pulp and paper and energy projects progress successfully.

6. A large tract of abandoned caneland on the big island of Hawaii has recently been purchased by Bishop Estates and bids have been solicited for a 10,000 ha planting of eucalyptus. More abandoned caneland could become available.

The probability is good that many of the SRWC projects being initiated by pulp and paper company will be successful. Company staff are contacting ORNL staff familiar with the SRWC research performed in each region, they are linking up with researchers in the regions, they are joining collaboratives and consortia established within the regions, and they are visiting and evaluating many of the successful commercial sites that have been established by early private sector adopters of the technology. The success of the projects will depend upon the ability of the company staff to quickly master the technical aspects of good site selection, proper site preparation and establishment techniques, and weed control techniques for SRWC. Considerably more information and expertise is available now than was available 15 to 20 years ago but success is not guaranteed, since firsthand learning is always required for adapting the techniques to the particular sites and climatic situations available.

Short-rotation woody crops have always been viewed as a multi-purpose crop. While some of the early commercial plantings were intended for energy end-use, such as the 20 ha planting in 1979 by the city of Hagerstown, Maryland and the 120 ha planting in 1981 by Reynolds Metal Company, most were planted by pulp and paper companies who were interested in new fast-growing sources of fiber. This trend has continued to today. Even where developers are interested in short-rotation woody crops as a dedicated biomass energy feedstock, there is a concern that the pulp and paper industry will tie-up the available supplies. Efforts are being made to resolve competition that might exist between energy and fiber end-users and to look for ways to build up the resource to meet the needs of both end-users. The acceleration in the development of the SRWC technology which is occurring by gaining the support and involvement of the pulp and paper industry, is anticipated to aid in the utilization of the technology for energy as well as for fiber.

One way of meeting both energy and fiber production goals is to encourage the pulp and paper industry to consider more seriously the co-production of energy from the wood resource. This could result, not only in total energy self sufficiency of the industry but also in an expansion of income generating products from the industry. Possibilities include not only excess electricity produced from the efficient burning of bark trash, sawdust and black liquor but also the production of liquid fuels or chemicals from the lignin components of the wood. The document "Agenda 2020: A Technology Vision and Research Agenda for America's Forest, Wood and Paper Industry" indicates the interest of the forest products industry in pursuing research of that nature (American Forest and Paper Association, 1994). The agreement being developed between the leaders of the forest products industry (as represented by the American Forest and Paper Association) and the Department of Energy is anticipated to lead to some innovative collaborative research that will address both energy and fiber supply issues.

Barriers to Using Biomass Crops for Energy

Perhaps the most significant non-technical barrier to using biomass crops for energy is the lack of creativity and negativity in attitudes. "Too many people know what can't be done" is the way it was recently stated by a biomass energy proponent. With limited federal and private research budgets, ideas have to gain the acceptance and approval of many people before money can be obtained to develop a concept or build a prototype. Many "experts" (including myself) are often constrained by their training and experiences. Their opinions fail to credit what can be accomplished by "can do" people determined to make a new idea work. Based on these expert opinions, improvements tend to be slow and incremental based on modifications of currently accepted technologies (or technologies in which the government or industry are already heavily invested). This approach is understandable, it avoids major mistakes, it involves major industrial players in the work, and it may be inhibiting the emergence of new, innovative ideas and concepts that could make a difference now.

Non-technical barriers to using biomass crops for energy which could change with policy changes include factors such as, the high cost of land suitable for high yield production, the low cost of competing fossil fuel feedstocks, the lack of established energy markets, the lack of adequate financing mechanisms, and the lack of information and technical support for the farmers. Some of these barriers can only be resolved with policy changes. For instance, the USDA farm commodities price support programs have a major impact on the value of cropland. If those price supports were to be reduced or dropped, land values would drop. Fossil fuel prices are not likely to change in the foreseeable future unless environmental considerations add to the cost of using fossil fuels. The lack of established energy markets and financing mechanisms is a chicken and egg problem which federal programs are attempting to resolve by initiating cost-shared demonstrations of integrated biomass energy systems. The inadequacy of information and technical support to the farmer is an issue which must be addressed by DOE, USDA and state groups interested in facilitating biomass energy.

Technological barriers to the sustainable commercial production of switchgrass for energy are minimal but improvements to assure the availability of low-cost supplies are still needed. Experience with demand for the seed for CRP plantings showed that seed availability could be a problem during a period of rapid scale-up. Since only a few of the varieties currently available produce the yields needed for economically viable biomass energy systems, the need exists for additional breeding and selection programs for the Midwest and the southeast to produce optimally adapted varieties for those regions. Establishment of the crop in a way that leads to optimal production in the first and second year does vary with different parts of the country and requires some attention for risk reduction. Development, testing and demonstration of optimal harvesting, and handling strategies for switchgrass crops that considerably exceed the yields normally found with forage crops is also needed. Since handling and storage losses can make a considerable difference in the delivered yields, continued attention to the best ways to minimize such losses is necessary for assuring the economics of using the crop for energy.

The biggest technical barrier to the widespread use of hybrid poplars, willows or other fast growing hardwoods on a large scale for energy is that the sites and climates conducive to high-yield production of hybrid poplars and willows is rather limited for the currently available superior clones. Additional breeding efforts and field trials are needed throughout the country to determine which sources and clones are most suitable for each region. The recent addition of a third crop development center for poplars by the DOE program, will help, but it will require the involvement of the private sector to establish the many expensive field trials needed. Similar work needs to be done for at least one or two additional fast-growing hardwood species to assure that adaptable, pest resistant woody crops are available for a broad range of locations in the U.S. and Canada. Additional research could enhance the sustainability of the techniques used for SRWC production and/or assure the public that current approaches are environmentally beneficial in terms of biodiversity, chemical reduction, etc..

Potential for Biomass Crop Contribution to Sustainable Energy Supplies

Biomass crop production technology is ready for application in an environmentally sustainable manner in many parts of the U.S. although significant opportunity exists for greater crop yield increases, and adaptability of the technology to a broader range of soil and climate conditions. One major question is how much land is available and what type of land is available. It was estimated by Graham (1994) that 8 to 16 million hectares of cropland could theoretically be converted to biomass production in the near future without displacing conventional crops in any significant way. This has been validated by more recent analysis done jointly by USDA, DOE and EPA (Ronigen *et al*,1995). However, the analysis being published by Turnure *et al*, (1995) also resulting from the same joint USDA, DOE and EPA analysis concludes that integrated biomass energy systems supplied solely with DFSS are not likely to be competitive with fossil energy systems until 2020. Even that is based on what might be considered an optimistic scenario for crop improvement and deployment, which assumes a well funded research program and considerable private sector cost sharing.

Stakeholder acceptance of the concept of growing perennial crops for energy is increasing. Emerging landowner/farm community acceptance is increasing as evidenced by the support of groups such as the American Corn Growers Association and the formation of the American Energy Crop Association in Peoria, Illinois. Likewise, utility acceptance appears to be slightly increasing as evidenced by the recent formation of the Utilities for Biomass Energy Commercialization Association, the continued participation of utilities in the Electric Power Research Institute's Biomass Working Group, the testing of biomass resources for co-firing by a number of utilities, and the participation of some utilities in biomass energy feasibility studies being conducted around the U.S. The bottomline for most utilities, however, is the relative cost of biomass energy compared to energy from fossil sources. Where utility interest in biomass exists, it is generally linked to a desire to provide a service to customers who have a biomass waste disposal problems or to a agricultural customer base which could benefit from local markets for biomass crops. Situations where independent power producers are considering using biomass energy systems also seem to provide an incentive for an established utility to consider the option. The acceptance of the general public and environmental groups is also beginning to increase as evidenced by the willingness of such groups to participate in national and regional roundtable discussion groups which particularly focus on the environmental issues surrounding the potential large-scale deployment of biomass crops.

As discussed in the previous section, policy factors are a significant barrier limiting biomass crops from providing a significant energy resource in the near term. Consideration of policy changes are occurring. The outcome of the 1995 farm bill will be a critical factor in determining the near term interest of the agricultural community in biomass crops. The U. S. Department of Agriculture has included biomass crops as an option in performing it's analysis to aid in the establishment of new farm policies. Numerous constituency groups are preparing analysis and statements on the desirability of policy changes which would encourage the establishment of biomass crops, this includes the American Forest and Paper Association which sees the benefits of additional fiber supplies being developed on agricultural land. Analysts have suggested that farm policy does not need to be radically changed but that relatively minor changes in existing programs could have a significant impact. One example is the continuation of the Conservation Reserve Program at some level with a modification to allow establishment and harvesting of crops for energy as long as the soil conservation objectives of the program continue to be met.

The successful demonstration of new biomass conversion technologies in the near future will be a critical factor in attracting investor interest and establishing markets for DFSS. Thus the program recently initiated by DOE, as part of the Climate Change Action Plan, to initiate cost-shared demonstrations of integrated biomass energy systems could have a major impact on how soon new biomass energy technology is implemented. The type of conversion technologies which are demonstrated will also have an impact on how quickly biomass crops become part of the biomass supply picture. Considerable risk is perceived to be involved in linking new crop production technologies and supply systems to new conversion technologies. Thus it will be difficult to gain acceptance or market penetration of biomass energy systems largely dependent on DFSS unless they are first demonstrated in systems where the risk is shared by the government, and the private sector. It is anticipated that the research and demonstrations which occur over the next 5 years will be critical to determining whether biomass crops become a significant contributor to sustainable energy supplies within 15-20 years or whether it will require 25-50 years. This will be a important time period for federal programs supporting biomass energy development to remain strong in their support.

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USING AN INTEGRATED FOREST THINNING/BIOMASS POWER STRATEGY TO SAVE NORTHWEST FORESTS

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Abstract

Wheelabrator Environmental Systems (WESI) has proposed to the United States Forest Service (USFS) and Bonneville Power Administration (BPA) to demonstrate an integrated forest thinning/biomass power generation system on USFS lands in Northeastern Oregon. The project, lasting 3 years, and thinning approximately 10,000 acres, would demonstrate the dramatic improvements in forest health and fire potential reduction that can be achieved by these techniques at no cost to the USFS. These techniques, developed over the last 10 years primarily on private lands in Northern California, involve marking the forest to remain following treatment, with the contractor carefully removing the excess material from the site.

To maximize value from the techniques, that region should possess sawmills, pulp and paper facilities, and biomass power plants. For this project, WESI will lease and refurbish an existing 6MW power plant owned by Blue Mountain Forest Products at Long Creek, Oregon. All residual fuel from the thinning will fuel this facility, with what saw timber and pulp chips result being sold into existing regional markets.

The project will demonstrate that, even on a small scale, the thinning can be accomplished at no cost to the USFS. The results will be shown to be highly desirable from a public policy and public acceptance standpoint. The operation and results will be studied by the Blue Mountain Natural Resources Institute to show that the resource has been improved in a variety of ways and degraded in none. The project will show the need for expanded contracting authority by the USFS to accomplish such work on a much wider basis.

The ultimate goal will be to demonstrate that the thinning techniques demonstrated should become the forest management practice of choice on overstocked, dead and dying USFS/BLM lands in the Pacific Northwest.

Introduction

In most locations it is said that only two things are for sure; death and taxes. In the Pacific Northwest (PNW), these are replaced by two things even more certain; the never ending debate over the future of the region's salmon and forests.

In recent years these debates have escalated to the point that extreme measures are being taken; measures that would have been unthinkable even a decade ago. As a consequence, Bonneville Power Administration (BPA) is struggling, changing and downsizing dramatically in an attempt to maintain its position as the region's preeminent bulk power supplier. On the forest side, a virtual moratorium exists while we try to figure out how to manage forests within the context of the myriad of environmental laws passed since 1970 that give free license to countless lawsuits and appeals. Like BPA, the United States Forest Service (USFS) is struggling to redefine itself, knowing that the way it used to conduct business is no longer acceptable, but not being sure what is acceptable.

While this plays out, the hydro resource is becoming less valuable and flexible, and more expensive, due to fish flushes and reservoir drawdowns. In the forests, the trees continue to grow while man debates, adding to the massive fuel loadings and overstocked conditions that are the result of nearly 100 years of fire suppression. In the summer of 1994 nature decided she had waited long enough for a solution and destroyed nearly 4 million acres of Northwest forests in a series of devastating fires. Unfortunately, with the forest conditions that exist, these fires burned so violently that they destroyed not only the trees, but the productivity of the soil, the watershed and the wildlife habitat value for hundreds of years.

Background

This situation cries out for some-long term common sense solutions. We have a candidate for a partial solution in some new forest management techniques that have developed in Northern California over the last decade. In the early 1980's, the forests of Northern California were similar to those of the inland PNW, characterized by overstocked, dead and dying stands at extreme risk of destruction by catastrophic wildfire. Massive outbreaks of insects and disease were common in the dense stands, where 10-20 times the historical stems per acre competed for limited amounts of water, sunlight and nutrients. Virtually all experts now agree that this was a product of eight plus decades of fire suppression, a period during which natural fire was not allowed to play its historical role of thinning and fuels reduction in periodic low intensity burns. These same experts also agreed that fire could not be reintroduced until forests were thinned and cleaned due to the threat of large stand destroying fires.

Into this situation was introduced the Public Utility Regulatory Policy Act (PURPA), which was especially well received in California. California had a combination of high avoided costs and state receptivity to alternative energy sources that made it a mecca to independent power producers. Nearly 50 contracts were signed for biomass plants, ranging in size from 5 to 50MW. Many of these were designed to use the waste products of California's forest products industry, the second largest in the nation following Oregon.

Once these plants were in place and purchasing fuel, a subtle change began to take place in traditional forest practices. Beginning on private lands, foresters realized that they now had an option to dispose of not only the traditional merchantable sawlogs, but the downed materials and numerous small trees that could now be chipped and sold as biomass fuel. In fact, a dense, overstocked stand at high risk of fire could be converted virtually overnight into a healthy, well spaced stand with a dramatically reduced risk of fire. While not a direct player in these new practices, the biomass plants were integral to the development as a market, for a substantial fraction of the total material removed from the site.

This new type of forestry requires a fairly radical change in mind set from the traditional view of a timber harvest as an opportunity to remove the best tree specimens from the site. In these practices, you diligently cruise the site looking for the best specimens, and you mark those to be left! Your purpose is to free the best trees from excess competition for moisture, sunlight, and nutrients. The contractor is then charged with removing all excess material from the site, and carefully sorting through it to obtain maximum value in terms of logs, chips and fuel. When coupled with input from wildlife biologists, hydrologists, soil scientists, etc., the thinning operation produces a forest that is more visually pleasing, productive, improved for willife habitat and watersheds, fire resistant, and closely resembling the region's forests prior to settlement.

These thinnings have now been studied for as long as 15 years. Results show that subsequent tree mortality can be reduced to zero by an aggressive thinning program, whereas up to 40% mortality over 10 years is occurring on unthinned sites due to excess competition (Figure 1). In addition, most thinnings favor the originally dominant Ponderosa Pine and Douglas Fir while removing higher percentages of the invasive White Fir and Incense Cedar. In reality, these thinnings mimic very closely the role played by natural fire up until this century.

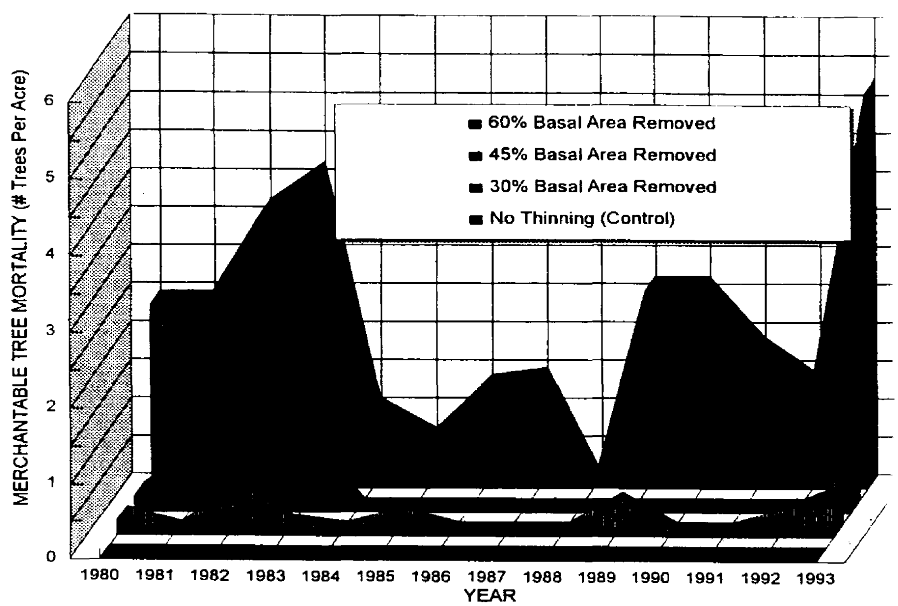


Fig. 1. Effects of thinning on natural mortality.
Data from a study on the Lassen National Forest

There have now been several instances where fires raging on unthinned lands have run onto thinned areas. Upon impact, the raging crown fires have immediately dropped to the ground in the thinned areas and been put out (whereas with the overgrown forests, firefighting was a spectator sport as long as the fire remained in the crowns). Many experts believe that the dense overgrown forests that exist today are the reason that acres burned annually in national forests have begun to rise again after eight decades of decline.

The techniques described above were refined by foresters, biologists and others fairly quietly until spring of 1994. At that time the California Public Utility Commission (PUC) issued its *Blueprint for the Future of Electric Utility Regulation in California*. That blueprint envisioned a system of direct access by electric consumers to electric suppliers, with the traditional electric utility supplying transmission and distribution service. The PUC suggested that purchasing decisions would be made by consumers solely on the basis of price. A head nod was given to renewables by mentioning the concept of "green pricing", but this was rejected out of hand by most players as being unworkable at the consumer level.

Because most biomass plants were still in the early years of their contracts, they were within the 10 years of fixed high rates that were a product of high utility avoided costs at the time the contracts were signed. When everyone compared these rates to those being thrown around as "market clearing prices" under the new system, it became obvious that biomass plants, as currently configured, could not survive.

Immediately, a groundswell of support began to build for saving the biomass industry in California. State agencies, including the California Environmental Protection Agency, California Department for Forestry and Fire Protection, Fish & Game, Air Resources Board, Food and Agriculture Board, Integrated Waste Management Board and California Energy Commission weighed in asking the PUC to modify their proposal on behalf of the biomass industry. Local and county governments in rural areas and local air quality officials weighed in as did several agriculture and waste management associations. Private forest landowners and the USFS supported continuation of the industry.

Some of the most vocal and articulate support came from the local bioregional councils, several of which were formed in California in response to President Clinton's advice at the Forest Summit here in Portland. He urged those in the region to form broad based local groups to reach consensus on use of public forests. These groups, which included local government, industry and environmentalists, had done just that, and found that the forest practices that had evolved with the participation of the biomass industry in California were the <u>one</u> thing they could agree on. This was the way forests should be treated, and they didn't want the PUC to mess with something good. The regional offices of some national environmental groups have also written in support of the biomass industry and the thinning techniques they make possible. As in other areas of society, you don't know how many friends you have until your existence is threatened.

The PUC threat also made us realize that we had structured the industry all wrong in California. Lulled by the initial high rates, we had placed the entire cost of the fuel supply infrastructure firmly on the electric ratepayer. The ratepayer was totally paying for the larger benefits brought to society by the biomass industry. Reworking that system in

California so that those who benefit pay directly will be painful and difficult, and the future for biomass plants is uncertain.

This brings us to our decision to propose a demonstration of these forestry techniques in the Pacific Northwest, including the integration of biomass electric power. It had early on become obvious that support for these forestry techniques was more widespread than we had known, and that the benefits to society and the forests are great. This might be just the thing to break the logjam that exists over the use of public forests in the PNW, one that has paralyzed the region. To simply continue to study and debate while the forests wait to burn does not seem a rational choice.

Secondly, based on our California experience, it seems possible to change the cost structure of the fuel supply, making biomass power much more cost competitive.

Proposal

Consequently, in August of 1994 we submitted a proposal to the USFS and BPA for a demonstration of an integrated forest thinning/biomass power generation system in the Blue Mountains of Northeastern Oregon. During this three year demonstration, we propose to thin approximately 10,000 acres of USFS land to supply fuel for an existing 6MW wood-fired power plant in Long Creek, Oregon.

The purpose for the demonstration is to show the benefits of these forestry techniques to the land, as well as to demonstrate that a sound set of economics can be developed around such an integrated system. The thought is to bring as many individuals and groups as possible to view the thinnings in progress, expecting them to conclude that these are the proper techniques to employ in PNW forests.

We knew going in that it would be difficult to attract the attention of the USFS and BPA on this proposal, since both were preoccupied with survival level issues, and we were not disappointed. The proposal languished until year end when we happened to contact the Blue Mountain Natural Resource Institute (BMNRI) in La Grande, Oregon. BMNRI, a cooperative research effort between the USFS and various universities, had received a copy of the proposal and was most interested in seeing the demonstration go forward. BMNRI agreed to provide the on-the-ground monitoring of the woods activities in the areas of silviculture, soils, watershed, wildlife habitat and biodiversity.

The concept we are working on involves selecting some of the worst examples of forest deterioration due to overcrowding, insects and disease and converting these areas into healthy, fire resistant stands. It is imperative that the project demonstrate that the economics of this activity are such that it can be accomplished, at worst, at no cost to the USFS. Based on our experience, we expect to be able to accomplish this easily, as shown on Figures 2 & 3, including delivering the biomass fuel to the power plant at no cost. It is key to have a contractor that can obtain the maximum value from the other products that are removed as excess to the needs of the site.

	Volumes			Values	Costs	Profit
	(MBF)	(GT)	(BDT)			
Logs	3	17	10	$900	$300	$600
Pulp Chips		25	15	$945	$630	$315
Hog Fuel		10	6	($63)	$150	($213)
TOTALS		52	31	$1,782	$1,080	$702

Fig. 2. Economic analysis of biomass harvesting operations. Scenario #1 (for multiple products on per acre basis)

	Volumes			Values	Costs	Profit
	(MBF)	(GT)	(BDT)			
Logs	4	23	14	$1,200	$400	$800
Pulp Chips		0	0	$0	$0	$0
Hog Fuel		29	17	($183)	$435	($618)
TOTALS		52	32	$1,017	$835	$182

Fig 3. Economic analysis of biomass harvesting operations. Scenario #2 (for multiple products on per acre basis)

Because of the small size and low efficiency of the selected power plant, it is not possible to operate this demonstration project on a break-even basis at the current market power rates of which BPA has indicated they would be willing to purchase the plant's output. Consequently, the parties have submitted a proposal to the U.S. Department of Energy (DOE) for supplemental funding of the project under its Biomass Power for Rural Development Solicitation. We should know this fall if we are successful in obtaining that funding. Figures 4 & 5 are the economics of this demonstration project based on successfully obtaining the DOE grant. In this scenario the USFS would receive $182 per acre treated (excess of revenues over expenses), even if no pulp chips were sold. Given the timing and location of the demonstration sites, however, it is likely that pulp chips will be marketable, raising the return to the USFS and increasing the number of acres treated substantially during the project.

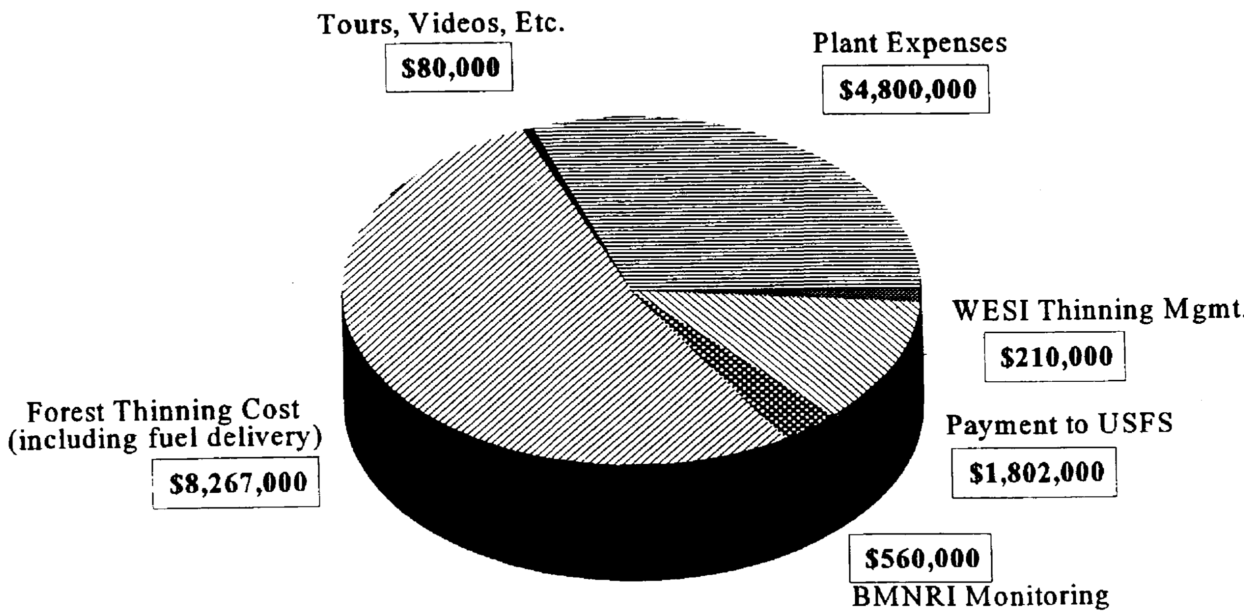
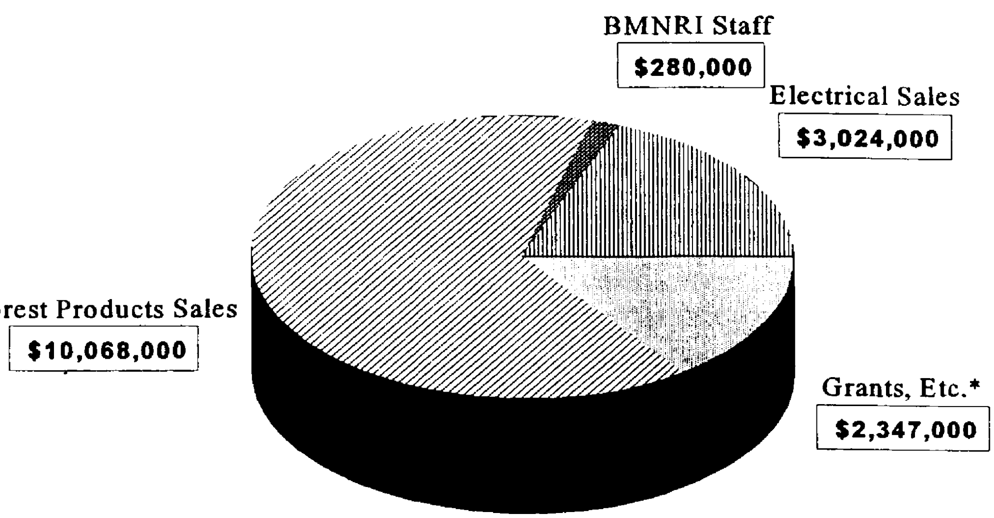


Fig. 4. Expenses



**Possible sources: DOE/DOA Biomass Rural Development Grant; USFS Sharing of Net Revenue; BPA Fish & Wildlife Funds; NWPPC Grande Ronde Watershed Funds; Lottery Funds, Economic Development Funds, Clean Chip Sales*

Fig. 5. Revenues

The small power plant at Long Creek will demonstrate nothing new in the area of biomass power generation. This 6MW Stoker fired plant historically burned mill waste from an adjacent sawmill and sold power to the local utility. It was shut down in 1992 when the utility bought out the contract. The power plant is a key component, however, in demonstrating the integrated nature of these forestry techniques, as it represents the appropriate disposal of the biomass materials after all higher valued products have been removed.

What we hope to gain at the conclusion of the demonstration project is a much wider acceptance that these types of integrated forestry techniques are the best solution to the dilemma of how to utilize and protect the public forests of the PNW. Rational individuals should rally around these techniques as being the only practical way out of a bad situation in the forests of the inland PNW. The BMNRI results should show that the forests are better off by any reasonable system of measurement.

Next Steps

This demonstration project has accomplished nothing unless it leads to a scenario in which these forestry techniques become adopted across wide sections of the inland PNW. But, if DOE must step in and financially support the power plants in each case, this simply will not happen. What is needed is a set of circumstances in which these integrated systems can be put in place and provide the benefits to the forest and the regional power system on a stand alone basis. Figures 6 & 7 are a projection of such a system using the woods economics described earlier.

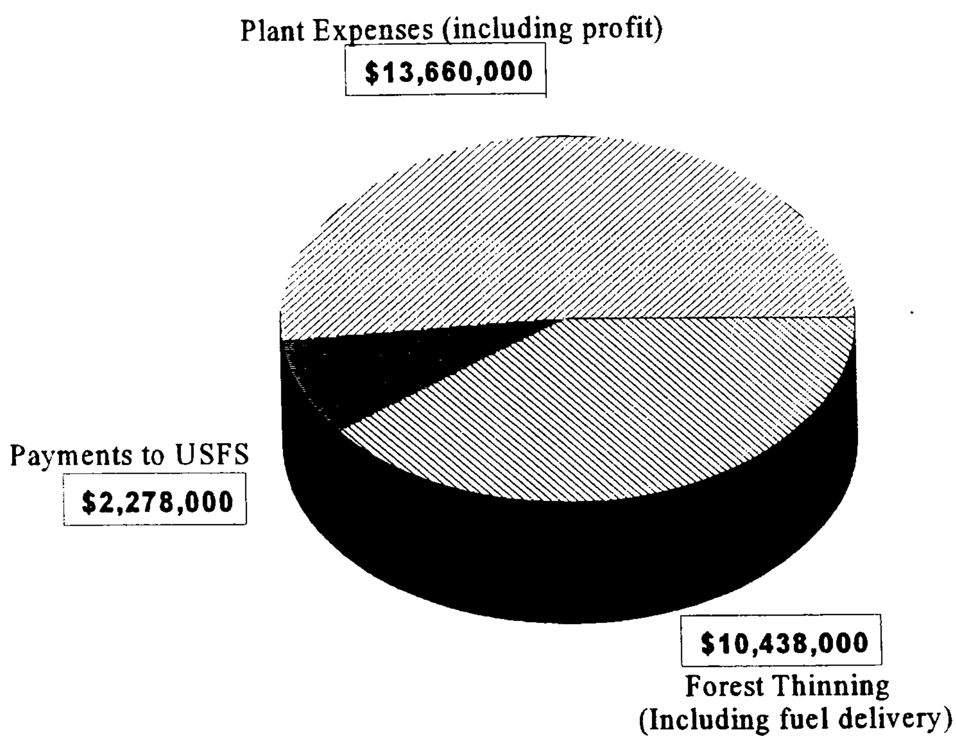


Fig. 6. Annual expense

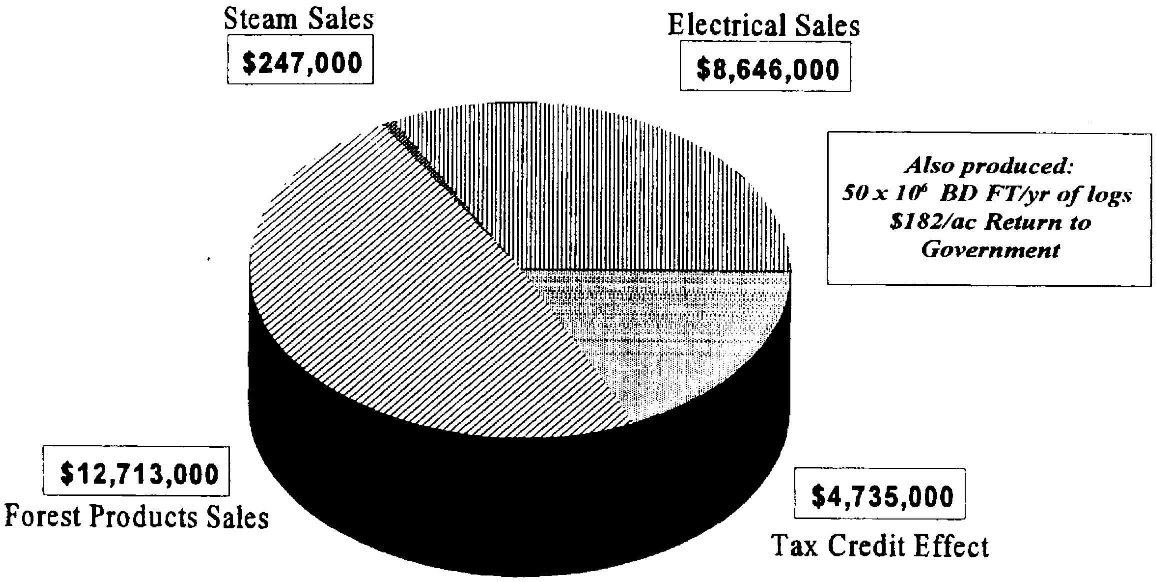


Fig. 7. Annual revenue

In this projection a series of 30MW plants fueled primarily by forest thinnings sells power to BPA at 3.5 cents/kwh in 1997. This size facility would support thinning activities on a typical USFS Ranger District of 300-400,000 acres, allowing the District to visit all sites on the forest needing thinning over a 20 year cycle. If, as the USFS has indicated, they need to thin 2-3 million acres per year to keep up with the growth of excess biomass, 100-150 of these plants would be required, representing 3,000-4,500MW of additional regional capacity. Accomplished over 15 years, this is an addition to 200-300MW per year, a minor addition regionally.

In order to make the leap from our little 6MW demonstration to 4,500 MW of biomass power over 15 years requires two key changes in federal law: 1) an expansion of the existing 1.5 cents/kwh federal biomass tax credit to the types of fuels that result from this system, and, 2) stewardship contracting authority for the USFS and Bureau of Land Management that allow them to enter into long term contracting relationships with land management contractors that cover acres treated rather than specific products removed.

The first of these items is needed to allow the resulting power to compete in the PNW in an era of cheap Canadian gas-fired plants. The second item removes the risk that fuel will not be available for the power plant and allows companies like ours to invest $50-60 million in each of these facilities.

Should the system evolve as I have described, it has another benefit which I have not dwelled on previously. Inevitably, in removing the excess biomass, the contractor comes across some material large and sound enough to be sold as sawlogs; typically 3-4,000 bd/ft per acre treated. These sawlogs, in addition to paying for the cost of the forest improvement, provide the raw materials to rejuvenate the forest products industry in the

PNW. On the typical ranger district described previously, these sawlogs would total 50-60 million bd/ft annually, an amount rivaling the district sale program prior to salmon screens, spotted owl designation, etc... The traditional annual sale quantity (ASQ) would then lose all meaning, to be replaced by acres treated annually as a measure of success in caring for the land.

This future scenario, while perhaps far fetched and a little unrealistic, is a scenario with virtually no downside. The land is returned to a condition not unlike that existing prior to settlement. Rural economies are protected and enhanced with new investment and new jobs. The forest does not go through a period when it is not a forest, thus it is appealing to the public. The power produced is a reasonably priced renewable source with other benefits in terms of carbon cycling, air quality, balance of payments, salmon protection and small increment additions. The acrimony over public forest policy is defused and channeled in a positive direction.

Current Status

So with all upside and no downside, this project should be humming along. Right! Currently, BPA has indicated a willingness to issue a short-term contract for this demonstration, but only at current market rates, and the local cooperative has indicated a willingness to wheel the power to BPA. The USFS has assigned the project to the Forest Health Team at the Region 6 Headquarters in Portland, and we are working with them to find an appropriate contracting mechanism and project scope. The Malheur National Forest staff is being called in to locate appropriate thinning sites.

We have a lease ready for signature that would allow us to lease the plant for the demonstration project. It will only require 60-90 days to put the plant in running order. In addition, significant local support has been gathered for both the project and the grant request. These include the Oregon Governor's Office, Oregon Department of Forestry, Wallowa and Union Counties, the Grande Ronde Model Watershed Project and several members of the Northwest Congressional Delegation.

It is our expectation that all elements will be in place to begin the project immediately following the announcement of grant recipients this fall. At the latest, we hope to be working in the woods and at the plant by early spring.

We have begun to work with Congress on the tax credit issue. Though we have not completed the analysis, we feel that there is enough benefit to the federal land management agencies in terms of income and lowered fire suppression costs to offset the loss of revenue via tax credits. This is a key point in selling the tax credit concept to Congress.

Stewardship contracting language has been drafted and is being included in long-term forest health related legislation, such as Senator Craig's S391. These concepts are in use on a limited basis in California, and only need to be expanded and broadened.

In summary, the integrated system that has evolved in California has demonstrated wide acceptance and numerous benefits, and is worth a try in the forests of the Pacific Northwest.

LARGE-SCALE BIOMASS PLANTINGS IN MINNESOTA: SCALE-UP AND DEMONSTRATION PROJECTS IN PERSPECTIVE

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Abstract

Scale-up projects are an important step toward demonstration and commercialization of woody biomass because simply planting extensive acreage of hybrid poplar will not develop markets. Project objectives are to document the cost to plant and establish, and effort needed to monitor and maintain woody biomass on agricultural land. Conversion technologies and alternative end-uses are examined in a larger framework in order to afford researchers and industrial partners information necessary to develop supply and demand on a local or regional scale. Likely to be determined are risk factors of crop failure and differences between establishment of research plots and agricultural scale field work. Production economics are only one consideration in understanding demonstration and scale-up. Others are environmental, marketing, industrial, and agricultural in nature. Markets for energy crops are only beginning to develop. Although information collected as a result of planting up to 5000 acres of hybrid poplar in central Minnesota will not necessarily be transferable to other areas of the country, a national perspective will come from development of regional markets for woody and herbaceous crops. Several feedstocks, with alternative markets in different regions will eventually comprise the entire picture of biofuels feedstock market development. Current projects offer opportunities to learn about the complexity and requirements that will move biomass from research and development to actual market development. These markets may include energy and other end-uses such as fiber.

Introduction

Minnesota is currently the site of two scale-up research and demonstration (R & D) projects for planting short rotation intensive culture hybrid poplar on private land. The projects are located in central Minnesota near Alexandria and in the northwest near Oklee. The purpose of these projects is to provide a base of experience to launch large scale commercial projects. This step toward larger scale plantings is possible because of more than 15 years of research, species screening and crop development of hybrid poplar. This research has involved many state, local and federal agencies. Universities and individuals alike have been involved in planning, research and development. Scale-ups such as the two described in this paper are the next logical step toward creating a market for wood for energy. Other scale-up projects of hybrid poplar have occurred such as those performed by the forest products industries in the pacific northwest United States. In most regions of the country, wood fiber markets are fairly well developed and identified. Wood for energy is not; especially hardwoods from trees grown for that end use.

It is important to understand the reasons for developing larger scale (R & D) projects, the kinds of information that is collected and data derived from this near-production kind of work, and to understand the development of potential markets and the persons or clients to whom benefits may accrue. When many diverse groups with interests in agriculture, forestry, environment and economics converge, complex interactions with opportunities for mutually beneficial work may come about. We attempt to draw from early experiences and document these carefully so information may be more easily transferred to those who could most benefit from this information.

Most of the remarks in this paper center on the Alexandria project, the one which the authors are most familiar with. Background and comments regarding the Oklee project are also provided as they relate to the Alexandria project.

The next sections of the paper outline the historical perspective from early work in Minnesota and Wisconsin. A third section takes a closer look at the Alexandria project. In the following two sections, we outline interest among private landowners, and specific lessons learned from the scale-up work, respectively. We conclude with a summary of current related work, and recommendations about future issues that are likely to arise.

Historical Perspective and Review

A review of short rotation woody crop (SRWC) work in the state adds some perspective to efforts at Alexandria and Oklee. Regional research into these crops began at the U.S. Forest Service (USFS) Research Laboratory in Rhinelander, Wisconsin during the mid-1970s. Dave Dawson and Ed Hansen led the SRWC research at Rhinelander. Many others were involved. These early efforts helped to build a geographically limited but technologically solid base of knowledge and interested parties.

From 1979 to 1983 the U.S. Department of Energy (DOE) Short Rotation Woody Crops Program at Oak Ridge National Laboratory supported research to evaluate the potential of peat lands for producing woody biomass under short rotation intensive culture. University of Minnesota researchers planted poplar (*Populus spp.*) and willow (*Salix spp.*) on peat land to measure growth rates and other differences between clones. Since the proposed end product was biomass for energy, the plantings were very densely spaced. Peat land was chosen as a site because it was assumed that using more productive land to grow energy was completely out of the question. Growth rates were low and studies ended in 1984.

Interest in SRWC slowly began to build in Minnesota. Collaborative work with the North Central Forest Experiment Station continued to be supported by the DOEs Biofuels Feedstock Development Program at Oak Ridge National Laboratory under researchers Janet Cushman, Jack Ranney, Lynn Wright and others. In 1986, the DOE through Oak Ridge issued a solicitation for cost sharing on 50-acre scale-up plantings which developed into USFS and DOE cooperation on research for a series of 10 and 20 acre clonal trial plots in Minnesota and surrounding states. Eleven of these locations are still closely monitored (Downing and Tuskan, Hansen et al., 1993, 1995). Studies including use of herbicides and cultural techniques were also conducted. Information and research results generated from these plots is used directly on the large-scale biomass plantings in Alexandria and Oklee.

Private sector interest in wood energy led to the choice of Minnesota as a site for the1986 USFS and DOE field trials. Northern States Power Company (NSP) was involved in the concept of growing trees to burn as fuel. An engineer on their staff, Dave Ostlie, promoted a vision of burning whole trees. NSP supported the project for a few years, but then withdrew their support, leaving Mr. Ostlie to form his own company to further explore the technology of whole-tree burning. Another private sector group interested in SRWC was the Electric Power Research Institute (EPRI). EPRI, which joined the DOE in supporting the early field trials, funded power conversion tests.

By the time the Minnesota Department of Natural Resources (MN-DNR) became involved in SRWC, work was already well under way. Involvement of the MN-DNR was inevitable because the DNRs role is to work directly with landowners whenever state or federal cost-sharing is available for tree planting. DNR field foresters provide technical advice to the owners and ensure that public monies are achieving their mission. A real problem when DNR became involved in 1986 was that they did not have any expertise on hybrid poplar and short rotation planting.

Oklee and Alexandria Large-Scale Biomass Plantings

Minnesota has two simultaneous scale-up projects that are very different in their approach and philosophy. In 1992, oil overcharge monies were appropriated for a 3,000 acre SRWC project. This evolved into what is now known as the Oklee project. It's original purpose was to provide feedstock for converting to ethanol or thermochemical fuels. Lack of a commercial partner delayed the project until late 1993, when a regional utility, Minnesota Power and Light (MPL), agreed to find a market for the wood (though not necessarily an energy market). Five hundred acres were planted in the spring of 1995, and the remaining 2,500 acres are scheduled for planting in 1996. Site productivity, grower security, and commercial viability (as evidenced by utility participation) are key factors in this scale-up project.

Providentially, during the summer of 1993, DOE, EPRI and others were seeking scale-up projects around the country. With the Oklee project on hold, the DNR sought funds for a 1000 acre project as a substitute. The DOE, through the Biofuels Feedstock Development Program, (successor to the Short Rotation Woody Crops Program) and EPRI provided $227,000 of the $341,000 total to fund the biomass project near Alexandria.

The Alexandria project picked up momentum that temporarily shifted from the delayed oil overcharge project. Conservation Reserve Program (CRP) land was available and federal cost-shares covered $62,000 of the establishment costs plus the annual rent payments. Non-CRP land was not used as CRP was partially cost-covered. Landowners were chosen from those that had indicated an interest. Fortuitously, the CRP allowed landowners to recontract their currently held CRP contracts on qualifying land for tree planting.

In 1993, all partners for the 1000-acre Alexandria project were financially committed in less than two months. Work began by mid-October 1993 and 500 acres of land near Alexandria was prepared for planting before the ground froze. The remaining five hundred acres had to be prepared during the spring of 1994. All 1000 acres were planted with hybrid poplar cuttings in spring 1994. Fourteen-hundred additional acres were planted in 1995 in a second phase. This included a replanting of 400 original acres that had proven unsuccessful due mostly to spring site preparation on heavy sod. To date, 19 landowners have enrolled nearly 1900 acres.

The Alexandria Project

Overall, the main goal of the Alexandria project was to test systems that were developed on smaller research plots in a scale-up context. Researchers recommended only five of the best clones of hybrid poplar for commercial out-planting. The rotation age was set at seven to ten years to allow the trees to reach a size that would fit into existing commercial wood markets if energy markets failed to materialize. The spacing for that rotation age (8 feet by 8 feet) requires about 700 trees per acre.

One of the early steps taken in Alexandria was to hold a meeting, or roundtable, where a variety of stakeholders would be represented. The group included project funders, landowners, researchers, end-users, environmental groups, and natural resource agencies. The purpose of the roundtable was to introduce the project and give stakeholders a chance to ask questions and provide input to the project. The roundtable was modeled after early work of the National Biofuels Roundtable (unpublished draft final report).

It was felt that the scale-up would provide a true test of landowner interest in SRWC. Cultural techniques, such as site preparation, planting, and tending would be tested. The method of dispensing technical advice to landowners using a combination of foresters, crop management consultants, vendors, and others was new and needed field testing and documented evaluation. Even the interaction between the various agencies involved in the United States Department of Agriculture (USDA) CRP was studied.

Not all factors could be tested. Yield was important, but because of a shortage of availability of the newest clones, maximization of yield would not be fully realized. Ultimately, sites were selected more based on environmental impact assessment than productivity. Migratory bird and a small mammal studies were begun and are still being monitored.

Alexandria was chosen for several reasons. Good land prices relative to expected productivity certainly was a factor. CRP rents averaged $40 per acre and there was a great deal of CRP acreage. It was also helpful to have an enthusiastic DNR staff forester stationed in the area office that successfully promoted the program to landowners. Product champions have proven very instrumental and effective in developing new technologies toward commercialization.

Another good feature of the Alexandria area was the availability of alternative markets. Three major pulp and paper companies expressed interest in the wood, although at this time growers do not have contracts for their wood in hand. From a landscape perspective, Alexandria also was suitable. Historically forested, the land was generally cleared for agriculture between 1880 and 1960. Biomass crops, it was hoped, would more closely mimic the natural forest processes than soybeans and corn could.

Interest Among Landowners

To gain more information about the landowners enrolled in the Alexandria project, a survey was commissioned by the Wes-Min Resource Conservation and Development Area. Questionnaires were mailed to all CRP participants with land in the Alexandria region. Five-hundred thirty landowners representing one-sixth of the CRP acres responded. Results showed that landowners were quite interested in alternative crops. Sixty percent of the respondents indicated an interest in planting trees. About 22,000 acres were offered by owners as land they would consider for planting SRWC (Hybrid Poplar Survey, 1994).

In Oklee, farmer response was so high that only three meetings were needed to secure 10000 acres; only 3000 were needed. The difference in Oklee was that the end market and user was known *a priori*. In both cases, it appears that about three times as many acres were needed to select the best quality land. For every 1 acre of land needed, 3 acres would have to be considered.

The Hybrid Poplar Survey also provided some interesting fiscal information. Landowners were overwhelmingly (75%) in favor of annual payments instead of a lump sum payment up front. 65 percent of the respondents were interested in forward contracts with an end-user. Interest in joining a wood grower cooperative was expressed by about half of the respondents.

Landowners had reasons beyond economic motivation for participating. It was clear they did need to see a return on SRWC plantings, but not necessarily top dollar compared to other cropping options. The land they enrolled in the poplar program was productive but inconvenient to farm. Some land had lower productivity for corn, but acceptable fertility levels for trees. Some producers possibly were trying to reduce their workload (average survey age was 59). Some landowners sought to diversify their crop base. In some areas the heavy use of the CRP has changed the local farm economy. Not all landowners were full-time farmers. A single economic criterion is that producers must be able to market the product to users at prices they are willing to pay. Coming to terms on that price is next.

Lessons Learned

Many lessons were and still are being learned on both projects. The lessons learned will be incorporated into future plantings and projects. In fact, some of the lessons learned and knowledge gained resulted in changes during the second phase of the Alexandria project.

A key factor to ensuring success is to provide technical advice to landowners. Private sector crop consultants were utilized in Alexandria. Their knowledge of annual crops and weeds was extensive, but training was needed to better prepare them for understanding competition and release among woody crops. The DNR state forestry office, as the project leader, is now providing the bulk of technical advice in coordination with others. However, any forester or consultant getting into SRWC would need to learn more about weed control among hybrid poplar crops. The Oklee project plans to rely heavily on crop consultants in the future.

Some lessons were learned regarding environmental issues. First, environmental groups are interested in participating. Unique resources need to be protected in all planting areas. The National Biofuels Roundtable (1994) was an attempt to foster a landscape approach to solving natural resource problems. Such cooperation usually involves trade-offs and always requires higher levels and sophisticated planning and communication among stakeholders.

As an example, one tract in each of the two projects was pulled from consideration after landowner agreement, before planting, because of concern about proximity to Nature Conservancy reserves. Maps of sensitive sites have since been provided by the Natural Heritage Program. A forester's willingness to work with a stakeholder like the Nature Conservancy will be a positive attribute needed in expanding current planting scope.

In general, landscape level issues can be addressed, but benefits or negative effects on landscape are directly related to project scale. For example, a 100,000 acre project within a 50 mile radius involves less than 2% of the land base. One should look at the appropriateness of the landscape for a crop such as hybrid poplars and discuss general landscape concerns and opportunities. It is, however, impractical to actually plan and implement the best location for each field on a landscape basis, especially on private land.

Finally, immense technical information was gathered. For instance, site preparation must begin the year prior to planting. Shifting from machine planting to hand planting in most cases would permit early growing cycle cross-cultivation. Hand planting costs are similar, but the method allows rows to "checked" or marked evenly for precise placement and planting which would afford cross cultivation later. Cross cultivation is a good option to control weeds within the row.

Standards for planting stock have been established in writing and are rigorously enforced. Planting small cuttings does not afford early season drought resistance before cuttings take root.

The Biofuels Feedstock Development Program at Oak Ridge National Laboratory funded a study of the plantation effects on small mammals and birds on a subset of the Alexandria sites. The initial results clearly demonstrate that biological diversity, while best in natural forest ecosystems, is still higher on SRWC lands than on agricultural food and grain cropped areas.

Summary and Recommendations

Researchers are the key to technology transfer. A consortium of hybrid poplar plant material researchers has been an informal research group, partially organized by several universities, forest research laboratories and the Oak Ridge National Laboratory. The Minnesota legislature recently approved a $200,000 grant through the Natural Resource Research Institute at University of Minnesota - Duluth. The money will be used with other partners such as the USFS Research Laboratory in Rhinelander, WI to expand research related to plant breeding of hybrid poplar specific to Minnesota's soil and climatic factors. This grant requires 2:1 private sector matching funds. There are currently only 5 clones selected for their superior growing habit and viability planted on 2000 acres. As production scale planting increases, more clones need to be developed and planted in test blocks for species screening. This will provide the numbers of species that will increase the chances for adaptability on a wider variety of sites and soils and decrease the probability of an outbreak of diseases or pests. Other aspects that will continue to provide necessary production scale information are herbicide trials and environmental and landscape level studies.

The scale-up venture underscores the need to develop a pool of vendors for successful SRWC implementation. Vendors prepare sites, plant trees, tend, and harvest. They might include a subset of the farmer producers or may be comprised of existing crop service or start-up companies. They need to be trained in details such as weed identification and control. They may need specialized equipment and licenses. Some subsidies to encourage a vendor pool may be beneficial.

Not surprisingly, end users play a big role in project success. At a minimum, there has to some viable market outlet for the wood. Scale-up and demonstration projects such as in Alexandria demonstrate that early phases of projects can rely on risk-takers and subsidies to get enough acres into the project. In the long-run, end-users must be viable and committed. Providing letters of general intent to buy wood is one method. Forward contracting is even better. The higher level of commitment greatly eases the process of involving landowners as was obvious in Oklee when recruiting of owners was achieved in just a few public meetings. Parties involved must have the perception that risk and costs are being shared among all participants.

Grower cooperatives have also been suggested for Alexandria. The cooperatives could market wood and carbon credits. Carbon and other tax credits are being considered in different areas of the country. Grower-producer cooperatives would also jointly own equipment and bid for services.

We are learning that end-users can "smell" a winner in SRWC. Traditional forest industries in Minnesota have become very interested and active based on research work originally done with energy as an end-use option. An agreement entitled "Agenda 2020", signed November 1994 by the DOE and the American Forest and Paper Association now sets the stage for promotion of industrial growth, energy efficiency, and international competitiveness while preserving the environment. Multiple end-users assure growers of robust market viability.

The scale-up and demonstration work has been given a significant amount of media and political attention. Biomass for energy and for traditional wood products has moved from the "idea" phase to "ground-breaking" reality.

More needs to be learned. New clonal development and testing of herbicides like Oust are examples. The bird and mammal studies need to be ongoing. It is also necessary to continue scale-up to keep the momentum of the nurseries and vendors going. We believe another 5,000 acres of scale-up to further test the infrastructure of vendors, advisors, nurseries, would be valuable. We believe the private sector is on the edge of implementing the SRWC technology using the knowledge and skills gained to date. Because scale-up projects provide actual data about successful sites, growers, users, decision-makers, and others will be able to further develop production technology and integrate end-use systems in markets.

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BIOMASS RESOURCES FOR ELECTRIC GENERATION IN THE PACIFIC NORTHWEST

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Abstract

Biomass fuels offer a unique energy resource for electric generation in the Pacific Northwest. They are produced as a coproduct from our needs for food, fiber, and structural materials. Many of the fuels are considered as waste products from the major manufacturing process and are available for the cost of transportation. About 1,055 PJ (1,000 TBtu) of biomass residues are generated each year in the Pacific Northwest.

Traditional sources of biomass fuels include forest residues, wood manufacturing residues, agricultural field residues, and municipal solid waste (MSW). Woody residues have a long history of being used for electric generation, especially from cogeneration facilities located at pulp mills. MSW facilities were built in the 1980s but interest has declined with the availability of large regional landfills. Forest residues and agricultural field residues are not used in the region but are used in increasing amounts for electric generation in California. Other biomass resources include spent pulping liquors, biogas from animal manure and landfills, and residues from fiber plantations. A major question addressed in this paper is the future availability and cost of biomass fuels.

Biomass fuels offer several environmental advantages. With the exception of MSW, they are inherently clean burning. Their low sulfur and nitrogen content permits burning without the need for acid gas scrubbers. Their carbon dioxide emissions on an energy basis are comparable to coal but there is one important difference. The biological growth of biomass fuels consumes carbon dioxide as part of the photosynthetic process and thus their net contribution to global warming is zero. The utility industry has increased its interest in biomass fuels because of the carbon dioxide advantages.

Introduction

Biomass fuels are defined as any organic matter that is available on a renewable basis including forest residues, wood product residues, agricultural field residues and processing wastes, animal wastes, agricultural and woody crops grown for fuels, and MSW. Their physical characteristics vary widely depending on the source. They may be high moisture content like animal wastes or low moisture like wheat straw, and heating values are related to their moisture content. The low energy densities, compared to coal or petroleum, limits the distance they can be economically transported. Biomass fuels are low in sulfur and nitrogen and have a minimal impact on the environment when burned correctly.

Natural resource-based industries play a strong role in the Pacific Northwest economy. The forest products and agricultural industries are dominant and they both generate large quantities of wastes that could be used for electric generation. The growing population generates additional solid and liquid wastes with energy potential. The type and source of biomass fuel varies widely within the region both on a spatial and temporal basis. In general, because these fuels have a low energy density they cannot be economically transported any great distance. Thus, the available supply of biomass fuel for a facility is local rather than regional.

This paper presents the methods used to determine the availability of biomass fuels for electricity production, the historical situation and the indicated trends. It updates a report used by the Northwest Power Planning Council to prepare their twenty year plan (Kerstetter, 1989). The biomass resources considered include forest residues, mill residues, chemical recovery boilers, agricultural field residues, animal manure, MSW, landfill gas, and dedicated energy crops. The quantity of material generated is estimated for each material from a historical perspective and a projection of future quantities. The historical data illustrates the annual variations that have been experienced. The projections are intended to show the direction rather than an absolute number. Finally, the quantity of materials available for electricity production are estimated.

The quantity of biomass fuels ultimately available for generating electric power is determined by several factors. The first consideration is the amount of material physically generated However, not all material is available for electricity production. There are often technical, environmental, and economic constraints limiting the quantity available for energy use. Environmental factors limit the quantity of forest and agricultural field residues that can be removed from the forest or field. There are serious technical difficulties with the combustion and agricultural residues that limits the quantity that can be effectively burned in a combustor. There are combined technical and economic factors that further restrict recovery. For example, the size of a piece of wood, the slope of the terrain, and the distance from a road all affect its collection cost The most common constraint is the cost of collection and transportation being greater than the energy user is willing to pay.

Forest Residues

Forest residues are a general term encompassing several sources of potential biomass fuels. All have the common aspect of being generated in a forest environment. The most common forest residues are called logging residues. The residues consist of all down and dead woody material existing on an area after timber harvest is completed. Economics limits the recovery of most logging residues. Generally, the cost of residue recovery for energy is subsidized by the benefits resulting for other purposes such as slash removal requirements or stand improvements.

The quantity of logging residues generated is directly proportional to the demand for commercial timber and the volume of timber harvested. Residues generation is calculated by multiplying the timber harvest volumes by a residue factor appropriate to the area harvested. These factors were developed by the U.S. Forest Service for each state in the region (Howard 1981). The quantity generated varies greatly between and within the states and over time. Historically, logging residues have not been used for fuel, other than firewood, and thus the only cost data available is that derived from the many demonstrations that have occurred over the past years.

The quantity of logging residue generated in the next 20 years will depend upon the harvest levels and quantity of residue generated per volume of harvested materials. Resource Information Systems, Inc. (RISI) predicts timber harvests for various regions of the country (RISI, 1994). Their predictions are based on projected national and international economic conditions, the demand for wood products, and the relative cost of supplying the materials by different regions. They predict a decline in harvest volume of twenty percent between current levels and the year 2015 in the region. The result will be a decrease in the quantity of logging residues generated.

Predicting the amount of logging residue that can be delivered to a specific user at a specific cost is a difficult task. A report prepared for the Pacific Northwest and Alaska Bioenergy Program gives logging residue supply curves for each county in the region (Envirosphere, 1986). This study serves as the basis for the cost and economic availability data in this report. The lowest cost materials are assumed to be removed first, and each additional volume will cost more to recover The quantity of logging residue that could be recovered up to a marginal cost of $3.13/GJ ($3.30/MBtu) in 1995 dollars, chipped and delivered 30 km (50 miles) to a potential energy site was calculated. The minimum cost of logging residues is $2.46/GJ ($2.60/MBtu) and the average will depend upon the specific supply zone. Additional materials would be available at increased costs. The regional average economically recoverable forest residue was about 19 percent of the quantity generated. This value was used to compute the quantities available in the future based on RISI's timber harvest projections. Table 1 shows the current and projected supply of logging residues using the methodology given above.

Table 1
Historical and Projected Forest Residues
Generated and Available for <$3.13/GJ ($3.30/MBtu)

	1986-1990	1991-1995	1996-2000	2001-2005	2006-2009
Timber Harvest, Mbf	18,780	12,800	10,900	10,500	10,160
Residue Generated, PJ	269	184	156	150	146
Residue Available, PJ	51	36	31	30	28

Mill Residues

Reduced timber harvests restricts the supply of timber which increases the price and makes the Pacific Northwest less competitive resulting in less market share. RISI projections of timber harvests and the projected markets for the timber. The overall reductions are obvious. Some of the more subtle changes are the decrease in plywood usage from 19 percent in 1983 to 8 percent in 2007. Residues from lumber and plywood processing will also decline as production decreases.

Residues are generated when timber is converted into lumber and plywood. Residues factors relating the quantity of residue generated per board feet of lumber produced and per square feet of plywood are available (Larsen, 1993). The quantity of mill residues generated were calculated using the RISI projections and the Larsen's residue factors. Projecting the future demand for residues is more difficult. This study assumes that the process energy required to dry lumber and plywood comes from the mill residues. RISI projected the residue demand for pulp production and we assumed that 0.45 Mg hog fuel/Mg pulp (0.45 oven dry tons of hogfuel per ton of pulp) is used for process energy. Combining the supply of residues and traditional demands for residues gives the results shown in Figure 1. The area graphs shows the past and projected supply and traditional demands of mill residues. The line shows the residues technically available for fueling electricity generation and equals the difference between the generated and demand curves. These numbers are for the region, and there will obviously be areas with a surplus of residues while others will experience a deficit. However, the trend is rather clear. The quantity of mill residues available for electric power generation will be decreasing over time.

Mill residues used for fuel have traditionally been available for the cost of transportation. This occurs whenever the supply of residues exceed the demands. If a hog fuel user pays the cost of transportation then the price will increase as the supply radius increases. When the supply radii of two hog fuel users intersect then the supplier of the residues has competition for his residues and may charge a fee. If only one buyer is available, the mill can either provide the material free or pay to dispose of residues. Since 1983, the regional average price paid for the residues has shown a good correlation with the supply of residues (Wood Resources International, 1994). Overall, the supply of residues will continue to decline, which means an increase in price.

The price paid by a particular facility is determined by the mills location, local availability of mill residues, and availability of other resources. For example, the Tacoma Steam Plant uses many sources of wood residues. In July 1994 they accepted urban land clearing debris at no cost and at the same time paid \$14.33/Mg (\$13/bone dry ton) for fir bark from mill residues. This is common at mills, no one price is paid for hogfuel.

Chemical Recovery Boilers

The pulp industry converts wood into fiber. Some processes grind the wood and others use chemical processes to separate the fiber from the other woody components. Chemical recovery boilers are used to recycle the chemicals, reduce wastewater discharges, and recover energy.

There are 39 recovery boilers in the region with an estimated steam capacity of 5.2 Gg (11.5 million pound) steam per hour (Weyerhaeuser, 1994). They vary in capacity and operating conditions. Six of the 20 mills in the region generate electricity from their recovery boilers. Two mills are currently adding electric generating capacity and will use steam from their recovery boilers. Scott Paper in Everett, Washington and James River Corporation in Wauna, Oregon are both installing new hog fuel boilers and taking the steam from their chemical recovery boilers to run through turbine-generators and produce electricity. Both mills formed partnerships with public utility districts to finance the projects.

The potential for generating electricity from the remaining recovery boilers is 230 aMW estimated by assuming a steaming rate of 13.6 kg/kWh (30 pounds of steam/ kilowatt hour). This steam rate was imputed by using known data from the mills currently generating electricity and taking an average. The actual rate will vary with each mills individual steam generating capacities and their steam distribution systems.

Municipal Solid Waste

MSW is generated as a result of consumption and is a function of population and economic activity. The quantity of solid waste generated can be calculated based on the population and a residue factor. A recent estimate was made of the quantity of combustible materials available for energy in the Pacific Northwest (Deshaye, 1993). This report assumed standard waste generation rates and that each state would achieve its recycling goals. The quantities of combustible materials available are 5 Tg/yr (5.5 M tons/yr) or 74 PJ (70 TBtu).

There are currently four MSW energy recovery facilities operating in the region with a combined capacity of 55 MW. They consume 6 PJ (6 TBtu) of MSW, or less than 10 percent of the quantity available. The future for new waste-to-energy facilities in the region depends on the cost of alternative disposal options and the local political climate.

Agricultural Field Residues

Agricultural field residues are a coproduct with the grains produced to meet the nation's and world's food demands. Grain and seed crops are the major crops in the region. Demand for these products are determined by population and the relative competitive position of this region in supplying grains. The quantity of residue generated depends upon the yield of grain produced and the residue factors for that particular type of grain. The residues available for energy depend upon the agronomic requirements for how much residue should be left on the ground to provide for erosion control and soil fertility requirements. The average annual quantity of residues available for fuel over the past ten years assuming 3.4 Mg/ha (3,000 pounds/acre) of residue were left for agronomic requirements was 8.1 Tg/yr (8.95 M tons/yr) or 141 PJ/yr (134 TBtu/yr). As with the other biomass residues, there is considerable variation within the various areas of the state and from year to year.

The quantity of agricultural residue that will be generated and available during the next two decades is assumed to be similar to what we have seen during the past decade. The cost for agricultural residues including collection, transportation, storage and fertilizers added to replace what would have been provided by the residues is estimated to be $35/Mg ($32/ton) or $2.08/GJ ($2.20/MBtu) (International Resources Unlimited, 1994). Combustion of agricultural field residues can result in severe fouling and has constrained the use of agricultural residues for direct combustion applications.

Biogas Production

Biogas is generated when organic material decomposes in the absence of air, i.e., anaerobic digestion. Biogas is composed of approximately 50 percent carbon dioxide and 50 percent methane. It is the metabolic product of bacterial consumption of organic materials. Two major sources of biogas in the region are animal manure and MSW landfills. The production rate of biogas is governed by moisture content, nutrients, and temperature.

Animal Manure

The quantity of biogas generated from animal manure depends on the number of animals, the manure generation rate per animal, and the manure management system. Dairy cows provide the major recoverable animal manure resource. There are about 540,000 dairy cows in the region (USDA, 1993). The manure generated by these animals has the physical potential of producing 58 aMW of electric power. If the economies of scale limit a heard size to greater than 500 , then the generating potential in the region falls to 16 aMW. The generating potential is based on the rule of thumb of 0.1 aMW per thousand head of dairy cows assuming current manure management systems (Moser, 1994).

Landfill Gas

Biogas is produced in landfills because the organic matter in the refuse is decomposed by bacteria under anaerobic conditions. Biogas production typically begins one or two years after waste placement and may last for decades. Biogas production may vary significantly from landfill to landfill and from area to area with an individual landfill. This variability is due to the importance of site-specific factors such as waste quantity and composition, moisture, temperature, and pH. About 70 percent of the waste placed in landfills is organic material composed of yard waste, household garbage, food waste, and paper. Today, only two landfills are converting landfill gas to electricity, both in Oregon. The Short Mountain Project has 3.2 MW of capacity and the Coffin Butte landfill has 2.2 MW under construction.

The Environmental Protection Agency (EPA) developed procedures to estimate the electric generating capacity at landfills based on measured biogas production rates (EPA, 1993b). Landfill gas production rates were recently assessed in Washington and Oregon (Deshaye and Kerstetter 1994 and International Resources Unlimited, 1993). The annual gas production from the 18 landfills in Washington and 5 landfills in Oregon is estimated at 350 Mm^3 (12,400 million cubic feet of biogas per year or 7.8 PJ/yr (7.4 TBtu/yr). This is equivalent to a generating capacity of 70 MW. Recently opened regional landfills in eastern Oregon and eastern Washington will add an additional 100 MW of capacity. The major barrier to the conversion of landfill gas to electricity is the low price for electricity

Dedicated Feedstock Supply Systems (DFSS)

DFSS are energy crops grown on agricultural land with the whole plant being harvested and utilized for the production of energy. Hybrid cottonwood trees have been identified as the preferred feedstock for the Pacific Northwest. This choice was partially based on the research done by Washington State University. The pulp industry has begun to commercialize the idea of growing fiber on a short rotation basis, 5-7 years. Traditional forests are harvested on a 50-70 year cycle. At the present time, there are nearly 10,120 ha (25,000 acres) of cottonwood farming operation in Oregon and Washington with over 20,240 ha additional (50,000 acres) being planned for development over the next several years. The Soil Conservation Service estimates there are over 105,260 ha (260,000 acres) in Southwest Washington suitable for growing hybrid cottonwood (Columbia, 1993).

The material harvested from this land will be used for making pulp. There are no plans to produce crops exclusively for energy. James River Corporation is currently harvesting about 405 ha (1,000 acres) per year of hybrid cottonwood trees. From each acre they recover 27.2 Mg (30 tons) of chips for pulping and 11.8 Mg (13 tons) of hog fuel that is used in their boilers for steam production.

The cost of producing DDFS is estimated to be $88/Mg ($80/ton). These figures are for pulp chips and were taken from a recently prepared business plan (Columbia, 1993). The $80/BDT ($4.70/MBtu) cost precludes their use for fuel. However, the residues are available for the cost of transportation, estimated at $16.50/Mg ($15/BDT) or $0.85/GJ ($0.90/MBtu). The plan concluded that 4,050 ha (10,000 acres) in Southwest Washington would be available from the landowners and the chip market would be available.

Summary

Table 2 shows current biomass prices and estimates of the amount of fuel that could be available in the future for electric generation. The cost of fuels will increase if the traditional demands for residues exceeds the supply. The residues are coproducts of our needs for food, fiber, and structural materials. The quantities given as "available" are not all based on the same constraints. Available forest residues are those recoverable for a cost less than $3.13/kJ) ($4.50/MBtu). Mill residues are those available after traditional uses are satisfied. Agricultural field residues are those available after leaving 3.4 Mg/ha (1.5 tons/acre) of residue on the field for erosion control. Animal manures are based on an economic herd size cut-off of 500 head of dairy cows. Dedicated crops are the residues left from dedicated crops grown for pulp. Recovery boilers, MSW, and landfill gas availability is equal to the quantity generated.

Table 2
Summary of Past and Projected Quantities of Biomass Fuels Available for Power (PJ/year)

	1986-1990	1991-1995	1996-2000	2001-2005	2006-2009	Cost 1994, $/GJ
Forest Residue	51	36	30	30	28	$3.13
Mill Residue	105	47	40	26	19	$1.33
Recovery Boilers	94	86	86	86	86	$0
MSW	74	74	74	74	74	($37.9)
Agricultural Field	141	141	141	141	141	$2.08
Animal Manure	2	2	2	2	2	$0
Landfills	6	7	17	19	19	$0
Dedicated Crops	0	0.8	2.5	3	3	$0.85

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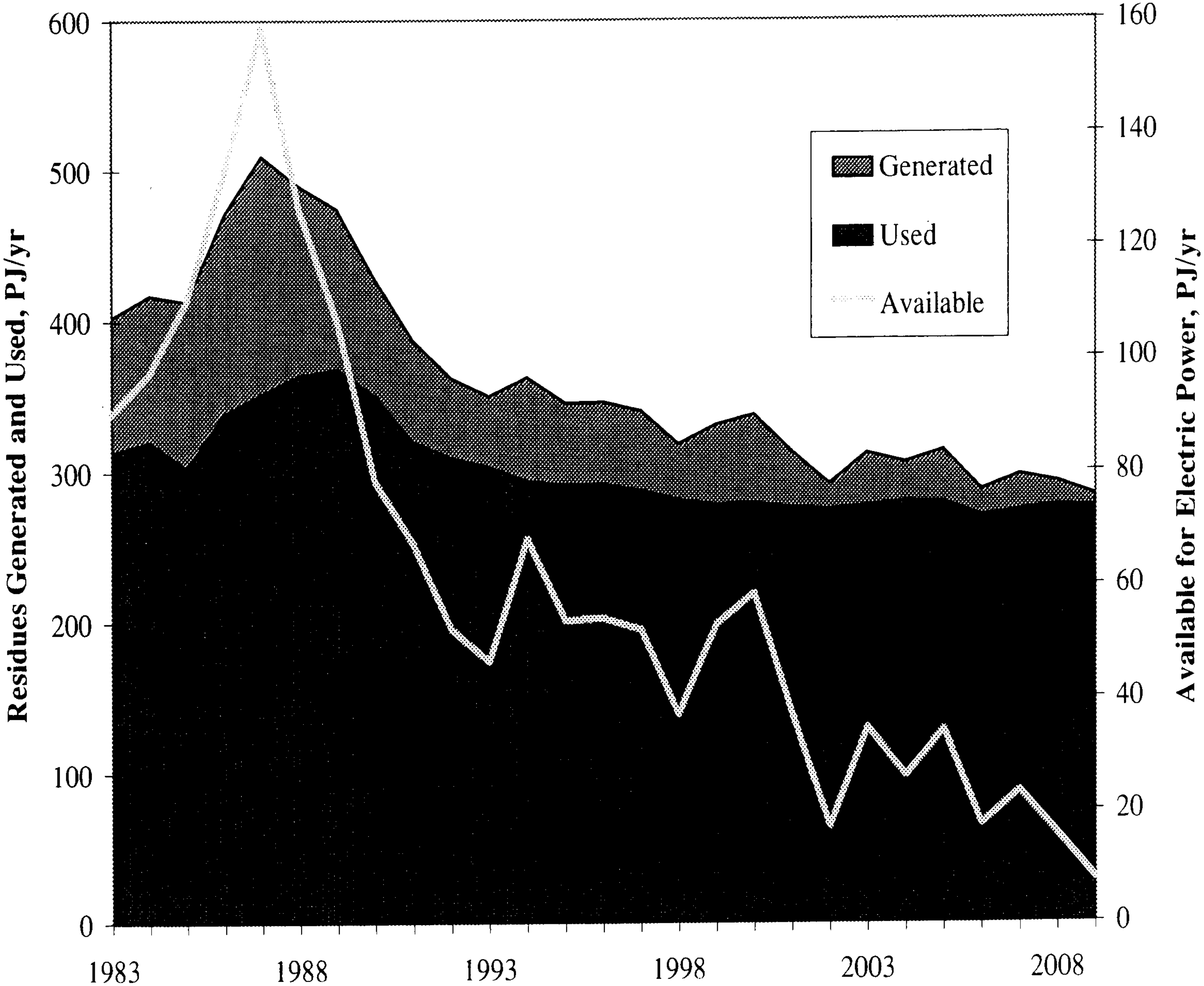

Figure 1. Mill residues available for electric power

SHORT ROTATION WILLOW COPPICE IN WALES: HIGH PRODUCTION UNDER ADVERSE ENVIRONMENTAL CONDITIONS?

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Abstract

The production of short rotation willow coppice in central Wales was once regarded as a vain hope rather than a distinct possibility. Research at the University of Wales, Cardiff, Field Station at Llysdinam in mid-Wales over the last four years has proven that it is possible to produce a commercially viable crop on very poor upland soils and at an altitude of almost 300m provided that lime and inorganic fertilizers are added. Because of the national need to find new routes for the disposal of sewage sludge, its addition to short rotation coppice serves the dual purpose of disposal and nutrient addition. Over the first two years of the sludging experiment, it was found that the addition of 300 m^3ha^{-1} of digested sewage sludge significantly increased crop weight, at least in the first year. Unfortunately, the crop yields did not reach those obtained using inorganic fertilizers at the same site but it is suggested that a repeated application regime might improve overall crop yield.

INTRODUCTION

Following a conference entitled " An Action Plan for Renewable Energy Sources in Europe" held in Madrid in 1994, representatives of many european countries and the European Commission signed the "Madrid Declaration", which states:
" In the year 2010, renewable energy sources can, and with collaborative efforts between all actors should, substitute the equivalent of 15% of conventional energy sources demand in the European Union... This could lead to the creation of 300 - 400,000 new jobs, increase the turnover of the renewable energy industry to 6 billion ECU and avoid the emission of 350 million tonnes of CO_2 each year."

The reality of 1990 revealed that renewable energy met 4.3% of the EU's primary energy need, mostly from large-scale hydroelectricity followed by biomass mainly from forest residues and energy-from-waste (ITT, 1995).

Much of Central Wales is very thinly populated, above 300m altitude, has Less Favoured Area status, is within Environmentally Sensitive Areas and is dominated by sheep grazed uplands , conventional coniferous forestry and water catchment areas. It has a considerable, but underutilised potential for renewable energy production from water, wind and biomass.

In 1935, Stapledon, the first Director of the Welsh Plant Breeding Station said "The most valuable product of the land, I am endeavouring to argue, is the human being.... The argument is frequently put forward that the cream of the country has been drawn to the towns, and only the unenterprising have been left to stagnate in rural districts....To hold to the country despite everything, and for the sheer love of the country, implies strength of character rather than the reverse". Sixty years on his final sentence holds true, but the modern pressures on the farmer and the countryside also demand enterprise and a forward vision towards diversification which will dispel stagnation.

In a report on the future of less favoured areas in Wales, Bateman (1993) concluded that, in the future, "farming methods will become more extensive, and at the same time land will be released from the industry. This will permit a move of forestry from poorer to better hill land but, with current returns, neither forestry nor agroforestry will develop to an extent which will provide significantly more employment." Whilst we would not question the foresight of the statement which agrees with our view that forestry/agroforestry, and in particular short rotation willow coppice, will become crops of increasing importance in upland Wales, we believe that growing willow coppice will go some way to help stem the decline in employment opportunities in the upland fringe. If so we will be approaching our aim of producing a socially, economically and environmentally valuable crop in a potentially harsh environment.

For two decades, short rotation willow coppice has been an accepted, if underutilised crop, in lowland Britain . It has developed a reputation, exacerbated by current government sponsored trials being limited to land below 200m, of a crop of little potential for agricultural diversification in the upland fringe. This is a reputation which we hope to show is not fully justified.

LOCATION AND METHODOLOGY

Elsewhere we have described the location, experimental layout and earlier results of our trials in central Wales (Hodson *et al* 1993; Hodson *et al* 1994; Lynn *et al* 1992; Lynn *et al* 1993 and Slater *et al* 1994). In summary, therefore, Carnau experimental site lies on the eastern flanks of the Cambrian Mountains and within an Environmentally Sensitive Area. It is a 1.5ha field, on poor quality gleyed soil, at an altitude of 296m and rainfall of about 1.5m per annum.

Our previous work using inorganic fertilizers had shown that he cultivar to be used in the present experiment was capable of producing more than 25 wt ha^{-1} at this site. The object was now to see if digested sewage sludge was capable of producing a similar result. After treating with glyphosate and ploughing, 15, 7m*7m plots were planted with willow cultivar *Salix x.dasyclados* using three replicates of five treatments which consisted of digested sewage sludge at the rates of 100, 200 and 300m^{3}ha^{-1} all with magnesian limestone, the limestone on its own and untreated controls (Figure 1). The magnesian limestone was included because previous experiments using inorganic fertilizers at the same site had shown its addition to be advantageous.

Directly after planting, application of residual herbicides took place to control emergent weeds. A mixture of 2.5kg simazine (a.i) ha^{-1} (as Gesatop at a rate of 5l ha^{-1}) and 1kg metazachlor ha^{-1} (as Butisan at a rate of 2l ha^{-1}) were applied using a knapsack sprayer. The crop was cut back at the end of its first year of growth.

RESULTS

a) Analysis of Digested Sludge

The sludge was from a local sewage works serving a rural community. Dry solids was 3.25% and pH in the range 5.0 - 6.0

Parameter	100 m^{3}ha^{-1} sludge equivalent
Total Nitrogen	174 kg ha^{-1}
Total Phosphorus	84 kg ha^{-1}
Total Potassium	7 kg ha^{-1}
Zinc	1.20 kg ha^{-1}
Copper	0.88 kg ha^{-1}
Nickel	0.05 kg ha^{-1}
Cadmium	0.003 kg ha^{-1}
Lead	0.05 kg ha^{-1}
Chromium	0.07 kg ha^{-1}

b) Biomass Production

The mean successful establishment across all the plots was 99.0% (range 95.9 - 100%). The mean annual production of *Salix x.dasyclados* for the four treatments and the control for both 1993 and 1994 growing seasons is shown in Figures 2 and 3.

One-way analysis of variance of the biomass produced during the 1993 season showed no significant increases ($p>0.05$) in biomass production due to treatment. Calculation of the least significant difference (LSD) showed that due to addition of $300m^3ha^{-1}$ sludge, a significantly larger amount of biomass was produced. Neither addition of magnesian limestone nor the two lower loading rates of sewage sludge led to a significant increase in production in terms of LSD although the graph shows a trend of increasing sludge additions leading to an increase in biomass production. The 1993 data required a logorithmic transformation in order to meet the assumptions of homogeneity of variance and normality of the residuals.

The 1994 data required no transformation. Analysis of variance and calculation of the LSD showed that there was no significant difference in the amount of biomass produced due to any treatment. Despite the statistical non-significance, a trend can be seen showing that both 200 and 300 m^3ha^{-1} sewage sludge additions produced double the amount of biomass as the control, the limed plots and also the plots treated with $100m^3ha^{-1}$ sludge.

DISCUSSION

The sludge used in these trials is fairly typical of that produced by rural sewage works in non-industrialised areas in that heavy metal concentrations are low and nitrogen levels might be slighty elevated by a cattle market and a pony trecking yard within the work's catchment.

Maxmum biomass production in both years was seen to occur in both years on plots that had received the highest loading rate of sewage sludge. The estimated mean production of these three plots was 1.3 and 6.7 wt $ha^{-1}yr^{-1}$ in 1993 and 1994 respectively. This production was significantly lower than than previous studies in the lowlands of England and the 25 wt ha^{-1} which we have obtained at the same site using inorganic fertilizers and lime.

During both the 1993 and 1994 growing seasons, increased sludge additions appeared to lead to increased biomass production. Significant differences were, however, only apparent during the 1993 growing season when the maximum loading rate led to a significant increase in biomass production. Since the sludge at Carnau was applied more than six months prior to tree planting, the increase in biomass production seen at the highest sludge rates was probably due to the slow release (mineralisation) of organic nitrogen over the duration of the first growing season but a process not sufficient to make the apparent increases in 1994 significant.

Although the application of magnesian limestone alone was seen to have no effect on biomass production, earlier experiments on site had shown that the addition of fertilizer (P&K) needed limestone additions in order to make the nutrients available to the willows. Such treatment led to a two-fold increase in biomass production in the establishment year. Because of space limitations, it was therefore considered more advantageous to use limestone as a treatment rather than three loading rates of sludge alone.

It is clear that, in this experiment, the application of digested sewage sludge at the maximum rate will result in increased biomass production of short rotation coppice willow. In spite of weed control measures weeds were a problem and may have been one factor reducing crop production. Although the crop production in this trial was too low to be commercially viable, our earlier experiments using inorganic fertilizers proved that an excellent yield could be obtained in a potentially hostile environment. It is suggested that annual applications of sludge might be one way to overcome the limitations of the present experimental application regime.

The use of sewage sludge on short rotation coppice may be of value simply as a means of waste disposal with its nutrient effects as a secondary advantage, but in the countryside, other wastes are readily available and our interests have now turned to the use of farm effluents as a source of nutrients for short rotation willow coppice.

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Carnau Sewage Sludge Trial Plot Assignment

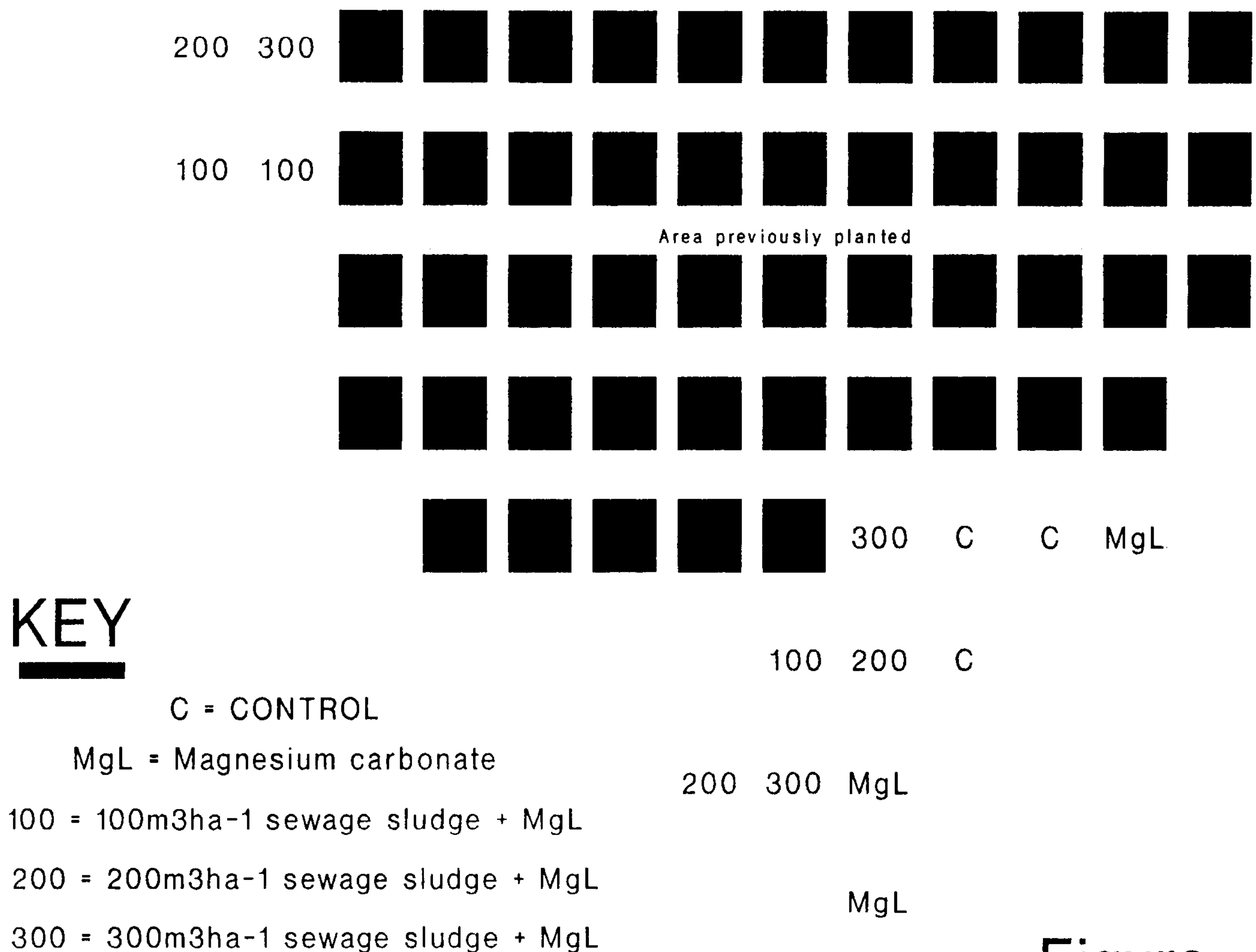

Figure 1

Carnau Sewage Sludge Trial Year 1
Biomass Production Jan'94 Fresh Weight

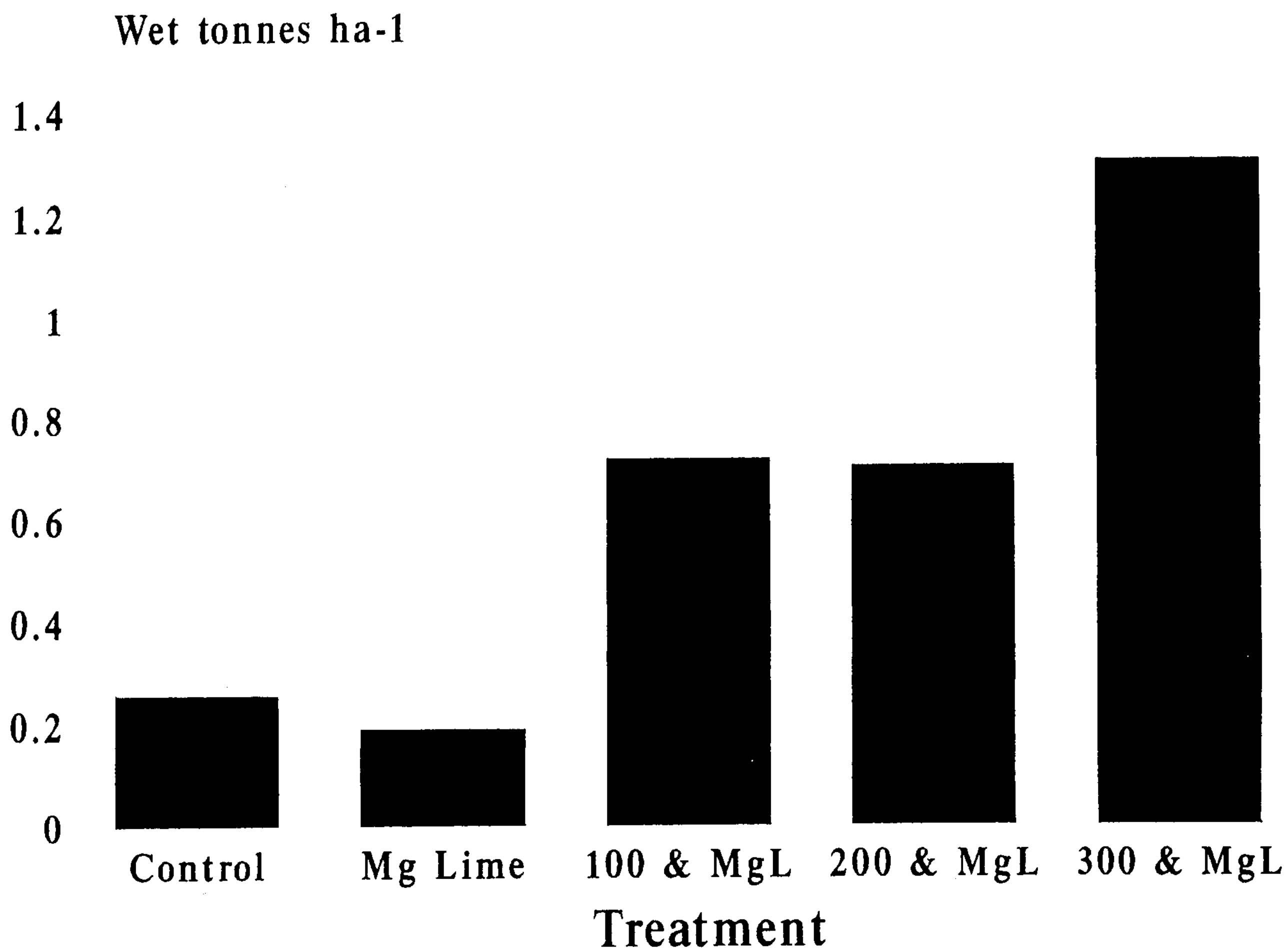

Figure 2

Carnau Sewage Sludge Trial Year 2
Biomass Production Oct'94 Fresh Weight

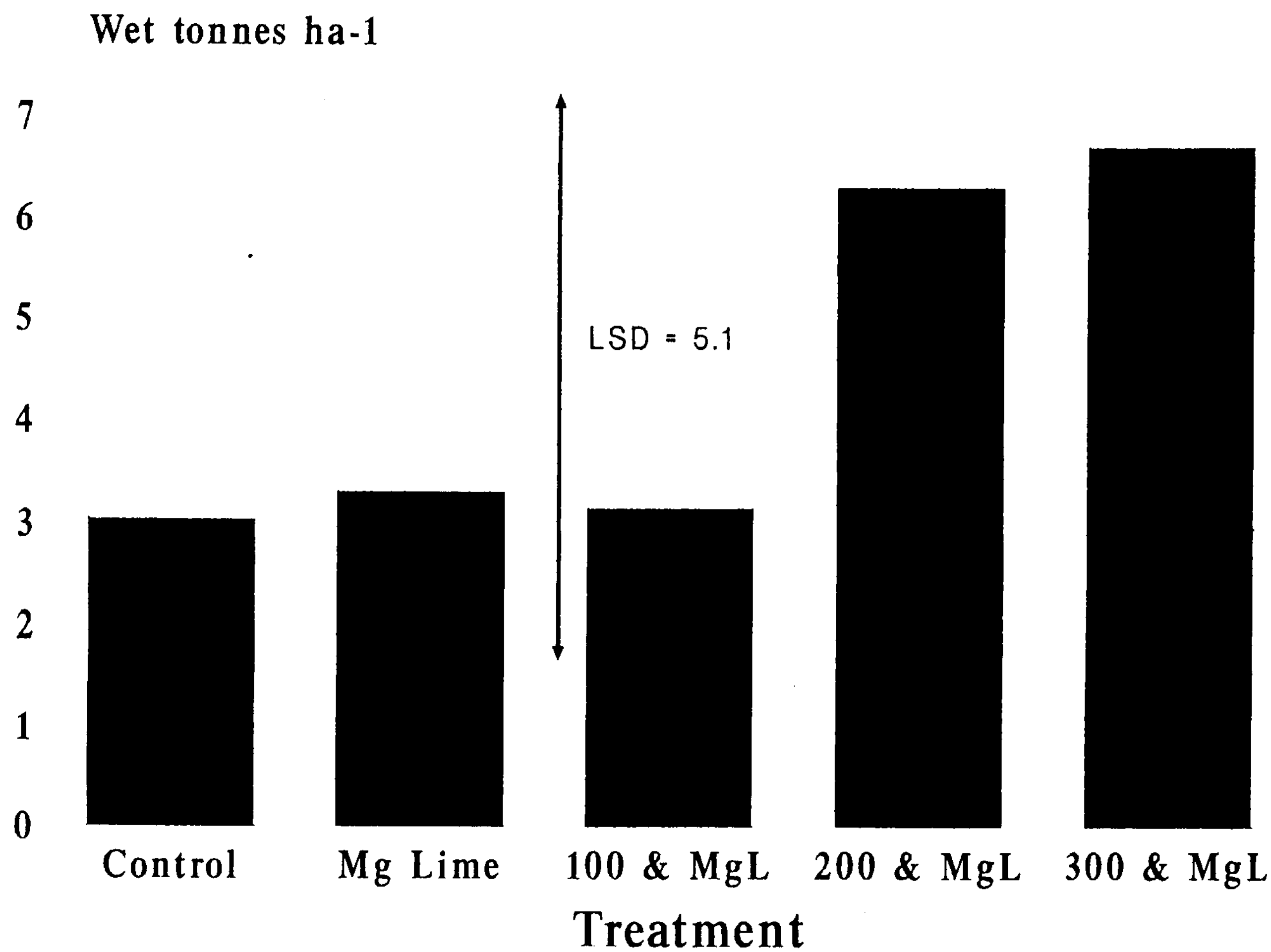

Figure 3

DETERMINATION OF THE POTENTIAL MARKET SIZE AND OPPORTUNITIES FOR BIOMASS-TO-ELECTRICITY PROJECTS IN CHINA

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Abstract

Efforts are currently underway to assess the market potential and prospects for the U.S. private sector in biomass energy development in Yunnan Province. Among the specific objectives of the study are to: estimate the likely market size and competitiveness of biomass energy; assess the viability of U.S. private sector ventures; assess non-economic factors (e.g., resource, environmental, social, political, institutional) that could affect the viability of biomass energy; and recommend appropriate actions to help stimulate biomass initiatives. Feasibility studies show that biomass projects in Yunnan Province are financially and technically viable. Biomass can be grown and converted to electricity at costs lower than other alternatives. These projects if implemented can ease power shortages and help to sustain the region's economic growth. The external environmental benefits of integrated biomass projects are also potentially significant. This paper summarizes a two-step screening and rank-ordering process that is being used to identify the best candidate projects for possible U.S. private sector investment. The process uses a set of initial screens to eliminate projects that are not technically feasible to develop. The remaining projects are then rank-ordered using a multicriteria technique.

INTRODUCTION

Energy use in rural China is typical of most rapidly industrializing developing countries. There is a household sector that is highly dependent on traditional biomass sources of energy -- firewood and agricultural residues (straw); and a growing industrial sector that meets its energy needs from both traditional and modern sources of energy.[1] In both of these sectors there are critical energy shortages that have led to worsening environmental conditions. The presence of shortages also means that existing industrial capacity is underutilized and/or good development projects are not proceeding at all.

The Joint Institute for Energy and Environment (JIEE) has been cooperating with Yunnan authorities since 1989 to investigate the possibility of using biomass to generate electricity.[2] Five teams of researchers have worked with Chinese experts and officials from Yunnan Province to plan, evaluate, and implement biomass-to-electricity projects.[3] Results of prefeasibility studies show that biomass-to-electricity projects in Yunnan Province are financially and technically viable. Biomass can be grown and converted to electricity at costs lower than other alternatives and can yield internal rates of return in excess of 15%. Study teams judged that biomass energy can ease power shortages and help sustain the region's economic growth, now averaging 8-10% annually.[4] Also, the external environmental benefits of biomass-to-electricity projects are potentially large, if replicated on region-wide scale. At present, tree plantations are being established in Yunnan Province and some plans are being made to co-fire existing sugar mills with bagasse and wood for year-round power production, and to construct stand-alone biomass-fired facilities.

Currently, there is a study underway to assess the market potential and prospects for the U.S. private sector in biomass energy development in Yunnan Province.[5] Among the specific objectives of this study are to: estimate the likely market size and competitiveness of biomass energy; assess the viability of U.S. private sector ventures; assess non-economic factors (e.g., resource, environmental, social, political, institutional) that could affect the relevancy of biomass energy; and recommend appropriate actions to help condition and stimulate biomass energy initiatives. This paper addresses the general approach that is being used to identify and rank-order biomass-to-electricity projects in Yunnan Province. The next section provides an overview of the screening and rank-ordering approach and some initial results.[6] The final section of the paper provides some conclusions and discusses future work.

APPROACH

A multicriteria screening model is being used to provide a rational and systematic procedure to identify the best investment opportunities for biomass-to-electricity projects in Yunnan Province. Past assessment efforts have identified two general types of projects. These are the conversion of agricultural processing mills (primarily sugar mills) to cogenerate heat and export power and the development of stand-alone biomass-to-electricity plants. The multicriteria screening model uses a two step approach:

- multiple technical screens (filters) to eliminate projects that are not technically viable,[7]
- and a multicriteria decision model to rank order the candidate list of biomass-to-

electricity projects. A flowchart of this general approach is shown in Table 1.

The results from the first step are a list of technically feasible or candidate projects. The technical screens include:

- unavailability of land for biomass plantations (or existing feedstocks) within a 25 km of a mill site;
- no need for power (e.g., availability of inexpensive hydropower);
- development cost is prohibited or the plant is too small;
- the area is too remote or inaccessible;
- there are lower-cost alternatives available (hydro or coal); and
- there is no local management capability and/or there is a lack of interest in biomass on the part of local institutions.

The projects that survive the screening are considered to be technically feasible in that they possess either a mill location or an area to grow plantation trees and there is minimum infrastructure and a perceived need for the power. At this step, no indication of viability has been made only technical feasibility.

The second step in the screening framework is to apply a multicriteria decision model to rank order the candidate projects. Multiattribute value theory (MAVT) is the most widely used approach for solving multicriteria ranking problems.[8] The basic MAVT decision model can be represented as follows:

$$V(X_j) = \sum_{i=1}^{n} w_i v_i(x_{ij})$$

where $V(X_j)$ is the overall additive value function for candidate biomass-to-electricity project j, w_i is the weight assigned to criterion I, v_i is the single attribute value function for x_i, x_i is the measurement on attribute I for project j, and n is the number of criteria.

The model is made operational in the following sequence of steps:

- define candidate projects (projects from initial technical screens) and decision criteria (hierarchy);
- evaluate each project separately on each criterion (scaling);
- assign weights to the criteria;
- aggregate the criterion weights and the single-criterion evaluations of the projects to obtain an overall measure of value or worth (e.g., additive value function);
- conduct sensitivity analyses;
- and rank order projects and determine potential market size.

In performing the actual ranking, four criteria are being used. These criteria are:

- the internal rate of return on the project,
- a biomass resource index,
- an index of the need for power, and
- a qualitative assessment of local capabilities to organize and implement the project.

Table 1. Flowchart of Multicriteria Screening Model Used to Identify the Market Potential for Biomass-to-Electricity Projects

■ Step I -- Screening analysis of potential sites and projects	■ Initial technical screens • Processing mill • Minimum resources • Availability of land • Infrastructure • Need for power
⇓	⇓
■ Model output	■ List of candidate sites and projects
⇓	⇓
■ Step II -- Multicriteria decision analysis of candidate sites	■ Multiple ranking criteria • Financial/economic • Resources • Need for power • Institutional support • Environmental quality • Development • Implementation index
⇓	⇓
■ Model output	■ Rank ordering of potential sites
⇓	⇓
■ Determination of market potential	■ Size of market indices (e.g., total MW, number of installations, etc.)

Once appropriate scaling functions are developed and each screened project is evaluated, weights are assigned to the criteria. Table 2 summarizes one rank-ordering of potential projects that is based on assigning a weight of 4 on internal rate of return, a weight of 3 on the need for power, a weight of 2 on local capability to organize and implement the project, and a weight of 1 on biomass resources.

Table 2. Preliminary Rank-Ordering of Biomass-to-electricity Projects in Yunnan.

Project	Rank-ordering
Mengla - cogeneration	1
Menghai - cogeneration	6
Tengchong - cogeneration	2
Guangnan - stand-alone	9
Funing - stand-alone	10
Luxi - cogeneration	5
Shuangjiang - cogeneration	8
Yongde - cogeneration	11
Xinping - cogeneration	12
Baoshan - cogeneration	7
Yongsheng (Qina) - cogeneration	3
Yongsheng (Maguohe) - stand-alone	4

This rank-ordering is preliminary and could change with refinement of the criteria indices. The ranking is also sensitive to the choice of weights.[9] Different weights will produce different rankings. Sensitivity analyses are currently being performed.

FUTURE WORK

Of interest to the U.S. private sector will be a rank-ordered list of specific candidate biomass projects. The JIEE is developing and refining this list as part of their current market assessment activities. Sensitivity analyses are also currently underway. Final projects results will be available this summer. In general, it was found that the two-step approach used to rank order projects was useful. It provided a systematic way to eliminate projects that would be difficult to implement and it provided a rational approach to prioritize specific projects for investment. However, the approach is data intensive and could not have been implement without the cooperation and support of the Yunnan Environmental Science Institute.

NOTES AND REFERENCES

1. Households account for about two-thirds of total rural energy use of which about 80% is firewood and agricultural residues (straw). Households consume slightly more than half of the rural commercial energy. About a quarter of total rural energy consumption or slightly more than half of the rural commercial energy goes to township enterprises. China's rural areas also produce a significant amount of the energy they consume.

2. The JIEE is comprised of Oak Ridge National Laboratory, the Tennessee Valley Authority, and the University of Tennessee. The JIEE is physically housed at the University of Tennessee.

3. The following major reports have been produced based on this cooperation: Perlack, R.D., J.W. Ranney, and M. Russell, *Biomass Energy Development in Yunnan Province, China*, Oak Ridge National Laboratory, ORNL/TM-11791, Oak Ridge Tennessee, June 1991.
Russell, M., D. Jantzen, and Z. Shen, *Electricity form Biomass: Two Potential Chinese Projects*, Joint Institute for Energy and Environment, University of Tennessee, Knoxville, December 1991.
Jantzen, D. and M. Russell, *Biomass-to-Electricity Projects in Yunnan Province, People's Republic of China*, Joint Institute for Energy and Environment, University of Tennessee, Knoxville, June 1992.

4. Yunnan has officially expressed its desire to attract foreign companies to boost its economy in several sectors, including energy (Yunnan Foreign Trade and Economic Cooperation Bureau). Yunnan, which is landlocked in a country where economic development is focused on the coast, has joined Myanmar, Thailand, Laos, Cambodia, and Viet Nam (collectively the Mekong Six) to promote greater economic cooperation and trade. The Mekong Six have plentiful and motivated cheap labor and abundant natural resources, but lack infrastructure including power.

5. The market assessment and identification of investment opportunities in Yunnan is being undertaken in cooperation with the Yunnan Environmental Science Institute, Kunming.

6. A full report of the results of the market study can be found in Perlack R. D., et al., *Opportunities for Biomass-to-Electricity Investments in Yunnan Province*, China, forthcoming.

7. The number of potential applications is large. In Yunnan there are over 75 sugar mills for possible cogeneration and 128 counties that could be sites for stand-alone biomass electric facilities.

8. A detailed discussion of multicriteria decision making can be found in Perlack et al., *Prototype Framework for R&D Decisions*, Working Draft, Oak Ridge National Laboratory, December 1994.

9. It was hoped that final results of the screening and ranking exercise would be completed in time for the publication of these proceedings. However, a final report on the determination of opportunities for investment in biomass-to-electricity projects will be available from the author.

BIOMASS ENERGY OPPORTUNITIES ON FORMER SUGARCANE PLANTATIONS IN HAWAII

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Abstract

Electricity produced from burning sugarcane bagasse has provided as much as 10 percent of Hawaii's electricity supply in the past. As sugarcane production has ceased on the islands of Oahu and Hawaii and diminished on Maui and Kauai, the role of biomass energy will be reduced unless economically viable alternatives can be identified. An empirical biomass yield and cost system model linked to a geographical information system has been developed at the University of Hawaii. This short-rotation forestry decision support system was used to estimate dedicated biomass feedstock supplies and delivered costs of tropical hardwoods for ethanol, methanol, and electricity production. Output from the system model was incorporated in a linear programming optimization model to identify the mix of tree plantation practices, wood processing technologies, and end-products that results in the highest economic return on investment under given market situations. An application of these decision-support tools is presented for hypothetical integrated forest product systems established at two former sugarcane plantations in Hawaii.

Results indicate that the optimal profit opportunity exists for the production of medium density fibreboard and plywood, with annual net return estimates of approximately $3.5 million at the Hamakua plantation on the island of Hawaii and $2.2 million at the Waialua plantation on Oahu. Sensitivity analyses of the effects of different milling capacities, end-product market prices, increased plantation areas, and forced saw milling were performed. Potential economic credits for carbon sequestration and wastewater effluent management were estimated. The favorable net return estimates and the carbon and wastewater credits suggest that commercial forestry ventures merit consideration for these sites in Hawaii. While biofuels are not identified as an economically viable component, energy co-products may help reduce market risk via product diversification in such forestry ventures.

Introduction

Hawaii is undergoing profound land use changes due to urbanization and tourism, heightened environmental awareness and conservation of island biodiversity, and transition from traditional plantation agriculture to diversified agricultural industries that enhance agroecosystem sustainability. To help plan for a future that is consistent with local values and to implement effective land-use strategies during this period of rapid change, decision support tools are urgently needed. Our research team has evaluated the feasibility of short-rotation forestry on former sugarcane and pineapple plantation lands to manufacture a variety of wood products, including biofuels from wood chips.

Short-Rotation Forestry Decision Support System

To provide useful information to those interested in short-rotation forestry as an alternative land use, our research team at the University of Hawaii has developed a short-rotation forestry decision support system (SRFDSS) (Liu *et al.*, 1992, 1993; Merriam *et al.*, 1995; Phillips *et al.*, 1993a, 1993b, 1994, 1995). This tool, which addresses both land suitability and land availability criteria, can estimate yields and delivered costs of *Eucalyptus* spp. at several scales (state-wide, county or island, and field). It features four integrated components: (a) empirical yield models of promising tropical hardwoods (*Eucalyptus* spp.) constructed using growth data, site characteristics, and management variables from field trials conducted throughout the state by scientists at the College of Tropical Agriculture and Human Resources (CTAHR) at the University of Hawaii at Manoa, the Hawaiian Sugar Planters' Association (HSPA), the U.S. Department of Agriculture Forest Service Institute of Pacific Islands Forestry (IPIF), and the BioEnergy Development Corporation (BDC); (b) a short-rotation intensive-culture system model of production costs, including establishment, maintenance, harvesting, transport, and storage; (c) the Hawaii Natural Resource Information System (HNRIS) geographical information system and database developed by researchers in the Department of Biosystems Engineering at the University of Hawaii to extend the analysis to areas where no field trials exist and to present results in map form; and (d) a linear programming (LP) model to determine the maximum net return from the optimized mix of plantation management options, wood processing technologies, and market prices identified.

The SRFDSS has been used to estimate yield and delivered costs of wood chips from hypothetical tree plantations on Kauai, Maui, Molokai, Hawaii, and Oahu to specific bioconversion facilities on each island (Phillips *et al.*, 1993a, 1994), as well as product yields and costs associated with manufacturing energy products (ethanol, methanol, and electricity) (Phillips *et al.*, 1995). The SRFDSS is capable of estimating yield and production costs of tree plantations managed for up to 40-year rotations, with (or without) commercial thinnings to provide a variety of wood products throughout the rotation to generate cash flow. The LP capability is used to identify the optimized mix of (1) *Eucalyptus* plantation management strategies (e.g., growing space per tree, rotation age, thinning regime, nitrogen fertilizer application, establishment, maintenance, harvesting, transport, and storage), including potential for carbon sequestration and use of wastewater for irrigation and (2) processing technologies (chip mill to produce hardwood chips for export , MDF mill to manufacture medium density fibreboard, veneer mill to produce plywood, and saw mill to produce lumber) for two specific potential plantation sites in the State of Hawaii. The land parcels that were modeled are the former Hamakua Sugar Company plantation (7,778 ha) on Hawaii and the Waialua Sugar Company plantation (6,790 ha) on Oahu.

Figure 1 is a schematic overview of the integrated forest products components that are featured in the analysis. Because *Eucalyptus saligna* (Sydney blue gum) was determined to be more productive and cost effective than *E. grandis* (flooded gum) for both Waialua and Hamakua plantations, this species was chosen for subsequent system model analyses to develop 84 different combinations of growing space per tree, rotation age, thinning, and N-fertilizer for input to the LP model. Optimal spacing and rotation age for *E. saligna* chip production on Waialua and Hamakua plantations were identified using the SRFDSS model. This information was used to develop graphs of optimized management strategies and biomass supply curves for both plantations as managed for chip production only. Maps depicting the yields and delivered costs of *E. saligna* chips for both plantations were generated using HNRIS and the SRFDSS model.

A literature search was conducted for information on technical specifications, performance data, scale, and capital, fixed, and variable operating costs of a variety of wood processing technologies. Information on product prices, carbon sequestration by tropical hardwoods, and wastewater quality and quantity were obtained. Linear programming development and results of net return estimates of the optimized integrated forestry operations at the Hamakua and Waialua plantations are presented below.

Linear Programming Model Development

Plantation management, wood processing technology, and end-product price variables were used to develop the LP model. Base and alternative cases were identified for the analysis (technical and economic assumptions in the LP model development as well as the results reported here are detailed in a manuscript being prepared for submittal to an appropriate peer-reviewed journal for publication).

Plantation Management Variables

The SRFDSS utilizes both intrinsic site conditions (elevation, temperature, solar radiation, rainfall, and soil nitrogen and pH) and manageable factors (growing space, rotation age, and N-fertilizer) to estimate mean tree diameter at breast height (DBH) and stand productivity, as well as costs associated with establishment, maintenance, thinning/harvesting, transport, and storage of wood material. Because growing space (planting density) and rotation age variables account for approximately 75 percent of the regression coefficient values for *E. saligna* yield, with N-fertilizer application being the next most important management variable, these three variables were employed in developing the plantation management options for LP analysis. Options for zero, one, two, and three thinnings were also incorporated into the LP model. A feller-buncher and grapple-skidder provided the least-cost harvesting system as described by Liu *et al.* (1992). Nitrogen fertilizer application was derived from BDC recommendations

(Whitesell *et al.*, 1992). For no-thinning options, a total of 0.15 kg N per tree is applied so that half of the fertilizer is provided at outplanting and the remainder applied at one-year after outplanting. For the thinned options, 0.04 kg N per tree is applied twice (at outplanting and at age one year), and an additional 50 kg N per hectare is applied at each thinning.

The SRFDSS was used to calculate yields and costs for the different plantation management options at each plantation. Mean tree DBH estimates were calculated by the SRFDSS at the times of various thinnings and final harvest (rotation age). These DBH data were used to determine log distribution to suitable wood processing mills, e.g., chip and MDF milling, veneer milling, and saw milling. This log 'split' or percentage distribution of log types based on DBH was accomplished by selecting a certain growing space per tree (10 m^2/tree) as being representative of the forest stand described in Table A.9.3 of Groome Poyry, Ltd. (1994).

For the plantation management options, the wood production yield and cost estimates developed using the SRFDSS are presented for (a) Hamakua plantation and (b) Waialua plantation. This information was used subsequently in the LP analysis to select the integrated forest products system (both plantation management option and wood processing technology and price option) that maximized net return on investment.

Wood Processing Technology and End-product Price Variables

The wood processing technologies used in the LP analysis are those featured in the *Hawaii Forestry Investment Memorandum* (Groome Poyry, Ltd., 1994) at the same and different plant capacity scales: (a) saw mill for sawn lumber of various quality grades; (b) veneer mill (Meinan "Aristlathe" with drier and press) for plywood production; (c) medium density fibreboard (MDF) mill; and (d) chip mill for hardwood chip export. Through an extensive literature search and numerous contacts with national and international experts, reasonable data for each of these technology/price variables were developed and characterized by (1) capital requirement at various production capacities, (2) product recovery and loss described factors, (3) operating costs, (4) annual depreciation rate, and (5) average market price at the plant gate.

Prices for wood products were derived from *Forest Products Prices, 1971-1990* (U.N. Food and Agricultural Organization, 1992) for plywood, MDF, and export chips. Sawn lumber prices were derived from *Asian Timber* as reported by Tisseverasinghe (1989). To calculate capital costs, an annual discount rate of 10 percent and an annual depreciation rate of 10 percent were used. Operating costs were calculated simply as a percentage of capital costs based on examples found in the literature.

Base Cases

Any of the wood processing/end-product price options used in the LP model contains a certain set of production processes, with a certain relationship between input and output for each process. The LP model chooses the optimal combination of these production processes including the optimal scale (production capacity) of operation. Base case #1 and base case #2 differ in processing plant capacity, with base case #2 having a chip mill, MDF mill, and veneer mill at one-half the capacity of base case #1 (the saw mill capacity remains the same). When the processing plant capacities are decreased, both capital and operating costs per m^3 of end-product increase, i.e., economies of scale are evident, and are estimated from reports in the literature.

Alternative Cases

Alternative wood processing/end-product price options were used in LP sensitivity analyses to determine the effects of +/- 20 percent price changes (alternative case #1), plantation land area tripled and three out of four mill capacities increased (alternative case #2), and forced saw milling (alternative case #3) with a fixed annual production of 4,000 m^3 sawn lumber in the integrated operation (all other assumptions remained the same as those in base case #1).

Linear Programming Application and Results

The utility and strength of the LP model are that a multitude of possible combinations of plantation management and production process options, which are subject to a set of resource limitations and production coefficients, can be evaluated accurately and expeditiously. The LP model finds the best possible combination for a given objective function, which may be either maximized or minimized. Because it is easy to change assumptions (coefficients and restrictions or bounds), the LP model facilitates the ability to conduct 'what-if' and sensitivity analyses. The LP software used for model calculations in this study was the LPS-867, Release 4.05 developed by Applied Automated Engineering Corporation.

The design criterion of the LP model was to maximize net return as the objective function. Net return was defined as the difference between the plant-gate revenue received from selling the products of the processing plants and the production costs of both the tree plantation and wood processing operations. The plantation and processing components were modeled as an integrated system, in which there are no internal prices (i.e., there is no income to the plantation operation and no cost for wood material to the processing operation). However, the LP model evaluates wood production costs in identifying the unique combination of a plantation management scheme and a set of processing plants that maximizes net return.

In the LP model runs, the plantation management options produce three different log types based on diameter size in various proportions. The logs may be utilized in one or more of four different types of wood processing plants. Within the scope of this project as the LP model exists presently, it describes a situation beyond the start-up period where both the tree plantation and the wood processing mills are operating at a steady state. This assumption means that the tree plantation is supplying a constant yield of logs of the same amount and log size distribution every year. This allows for maintaining a constant work-force, and for providing the processing plants with a stable, steady source of raw material. The LP model considers planting, thinning, and harvesting a certain number of hectares each year when selecting the optimal plantation management option. This number of hectares is equal to the total plantation area divided by the number of years from planting to final harvest (rotation age) for each particular option. The processing technologies are also modeled as a steady-state operation, as long as other variables, e.g., prices, are constant. Therefore, LP model calculates net return estimates only at a point in time after the start-up period is over. In addition to the revenue from the production of wood products, revenue may be obtained in the future from a "carbon sequestration credit" or from a "wastewater credit."

Results of the LP model calculations were developed for the base and alternative cases as annual end-product production (1000 m^3/yr), net return (1000$), and carbon and wastewater credits (1000$) for both plantations. Also, the plantation management option and the wood processing technology and price option selected, area harvested (ha), harvested yield (1000 m^3), net return per end-product unit ($/$m^3$), net return increase per unit required for the processing technology to become competitive ($/$m^3$), shadow price of land ($/ha), and carbon sequestered in end-products (Mg C) are featured. By applying various restrictions either on the resources (e.g., land area available) or directly on the amount of end-product produced by each wood processing mill, sensitivity analyses were performed. In the two base cases, mill capacity was varied to determine the effect of plant processing scale on net return. In the alternative cases, the effects of price change, expanded plantation size and increased plant processing capacity, and forced saw milling were featured. Table 1 summarizes the annual net return results for all cases. Discussion of the results are presented by plantation below.

Table 1. Net Return Estimates of Base and Alternative Cases for Potential Integrated Forestry Operations at Former Sugarcane Plantations in Hawaii.

Linear Programming Option	Hamakua Plantation, Hawaii (Annual net return)	Waialua Plantation, Oahu (Annual net return)
Base Case #1	$ 3,490,000	$ 2,211,000
Base Case #2	$ 1,085,000	$ 836,000
Alternative Case #1a	$ 8,615,000	$ 5,353,000
Alternative Case #1b	[none; negative solution]	$ 12,000
Alternative Case #2	$23,390,000	$14,522,000
Alternative Case #3	$ 3,307,000	$ 2,028,000

To determine "how far" a certain non-selected production process is from being selected as part of the optimal solution, the LP model calculates the quantitative amount by which the contribution of the non-selected production to the objective function must change to become selected. This amount is expressed as the positive price change in dollars per end-product unit that is required for one of the non-selected productions to become selected as part of the optimal solution. This LP output is reported as net return increase per end-product unit required for the processing technology to become competitive. For example, in base case #1, for export wood chips to become competitive the net return would have to be $82/m^3 ($28/m^3+ $54/m^3), and the net return for sawn lumber would have to be $110/m^3 ($64/m^3+ $46/m^3).

Another interesting output feature from the LP model is the shadow price of land, which is the increase in annual net return if one more unit of land is added ($/ha). For example, in base case #1, each additional hectare of land would generate $449/ha at Hamakua and $326/ha at Waialua. Considering the final harvest times, the total increase in net return would be $8,980 ($449 X 20 yrs) over the 20-year rotation at Hamakua and $4,890 ($326 X 15 yrs) over the 15-year rotation at Waialua.

Hamakua plantation

For base case #1, the annual net return is $3,490,000, where 35,000 m^3/yr of MDF and 22,000 m^3/yr of plywood are produced. Base case #2 features a 50 percent reduction in mill capacities with the same quantities of MDF and plywood produced as in base case #1 (in either case wood supply is the limiting factor, not mill capacity). The results of base case #2 indicate that the annual net return is approximately $1 million. This decrease in annual net return is attributed to diseconomies of scale associated with the smaller processing plants. For alternative case #1, a +20 percent increase in end-product prices increases the annual net return to $8,615,000, and a –20 percent decrease in prices results in a negative annual net return. By tripling the land area to 23,334 ha and utilizing processing mills with larger capacities, the LP model reported the annual net return to be $23,390,000. While economies of scale would be expected to improve plant processing return on capital, this is not necessarily the situation for the expanded plantation operation because of longer hauling distances and greater variability in site productivity. For alternative case #3, in which the LP model was forced to produce 4,000 m^3/yr sawn lumber, the annual net return is $3,307,000, or $183,000/yr less than without forcing the saw mill. The disadvantage of "losing" the $183,000/yr may be countered by "gaining" product diversification to hedge against market risks.

With 45 percent of stem dry weight stored as carbon (Evans, 1992), the potential for carbon sequestration in planted trees through final harvest at Hamakua (base case #1) is approximately 290,000 Mg C. A linear relationship between tree age and carbon sequestration is assumed for the purposes of this analysis because the trees are harvested before asymptotic stage of development. Therefore, dynamic growth of trees (life cycle) is not considered. The carbon sequestered annually in end-products is estimated to be 12,825 Mg C/yr. If a carbon credit of $10/Mg C is applied, approximately $128,000/yr could be added to the annual net return.

Waialua plantation

For base case #1, the annual net return is $2,211,000, where 21,000 m^3/yr of MDF and 14,000 m^3/yr of plywood are produced. With the reduced mill capacities (but the same quantities of MDF and plywood produced as in base case #1), base case #2 results indicate that the annual net return is $836,000. As for Hamakua, this decrease in annual net return is due to scale impacts of the smaller processing plants. For alternative case #1, a +20 percent increase in end-product prices increases the annual net return to $5,353,000, and a –20 percent decrease in prices decreases the annual net return to $12,000. By tripling the land area to 20,370 ha and utilizing processing mills with larger capacities, the annual net return increases to $14,522,000. However, for the same reasons as explained for Hamakua, this amount is artificially inflated because longer hauling distances and greater variability in site productivity are not accounted. For alternative case #3, in which the LP model was forced to produce 4,000 m^3/yr sawn lumber, the annual net return is $2,028,000, or $183,000/yr less than without forcing the saw mill. Again as with Hamakua, the addition of the saw mill to increase end-product diversification may help hedge against market risks.

With 45 percent of stem dry weight stored as carbon (Evans, 1992), the potential for carbon sequestration in planted trees through final harvest at Waialua (base case #1) is approximately 152,000 Mg C. The annual carbon sequestration represented in end-products is approximately 7,875 Mg C/yr. Given a carbon credit of $10/Mg C, the annual net return would be increased by $79,000. The potential use of wastewater effluent from the Schofield-Wheeler military bases and City and County Wahiawa and Whitmore Village sewage treatment plants to irrigate the Waialua plantation was investigated. Based on effluent deliveries from Wahiawa reservoir estimated at 2.5 million gallons per day, MGPD (9.5 million liters per day, MLPD) from the Schofield-Wheeler military bases, 1.7 MGPD (6.5 MLPD) from the Wahiawa sewage treatment plant, and 0.25 MGPD (0.95 MLPD) from the Whitmore Village sewage treatment plant, the total wastewater volume is approximately 4.5 MGPD (17.2 MLPD). This wastewater volume is approximately 10 percent of the 45 MGPD (174 MLPD) total irrigation rate applied to the Waialua plantation. The total irrigation volume represents an additional 0.8 inches or 20 mm (5-10 percent) of annual rainfall received at Waialua. With a wastewater effluent NH_3-N concentration of 7 ppm (mg/l) applied to the 6790-ha plantation, the additional nitrogen fertilizer contribution is approximately 1.4 kg/ha/yr. Regarding the additional input of water, the yield response of *E. saligna* is estimated to be less than a 5-percent increase. While the additional N input may enhance tree growth, the small amount is considered to have a negligible effect on stand productivity. However, as a means to dispose of wastewater, the opportunity to procure a wastewater credit of $1,350,000/yr is a significant bonus.

Conclusion

The utility of the SRFDSS developed previously (to estimate yield and delivered cost of tropical hardwood from parcels of land identified as both suitable and available for species-specific tree plantations in Hawaii) has been extended via linear programming capability (to estimate net returns of optimized combinations of wood products from specific plantations). The analytical results provide decision-makers who are contemplating alternative land uses on Hamakua and Waialua plantations readily useful information for scoping forest product investment strategies. The net return estimates for both plantations suggest that commercial forestry ventures merit consideration at these sites in Hawaii. Energy co-product(s) as part of potential forestry ventures will be determined primarily on their demonstrated contribution to net return on investment and secondarily to reduced market risk via product diversification.

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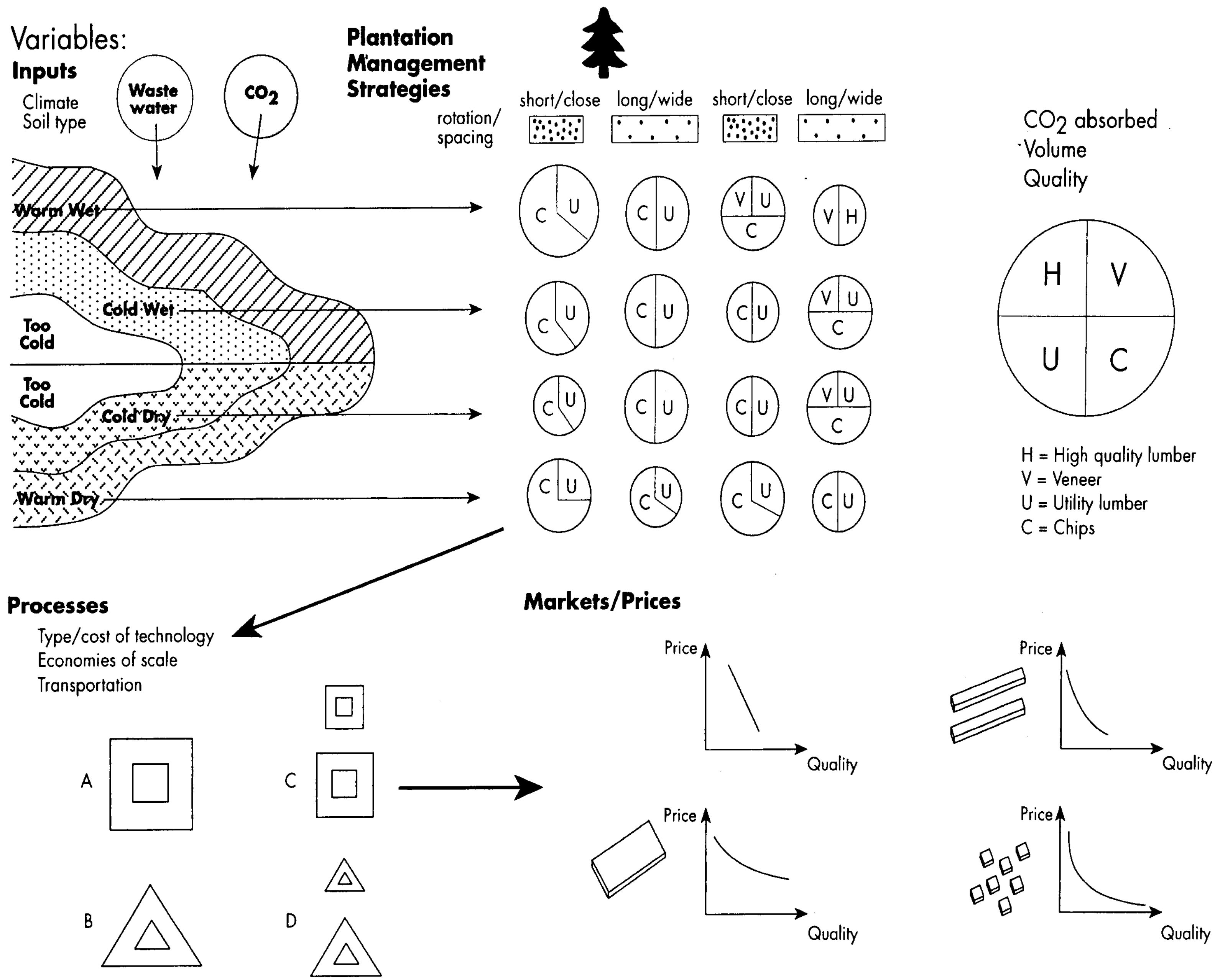

Fig. 1. Optimizing an integrated forest products operation (schematic overview).

TECHNOLOGIES FOR DELIVERING FOREST BIOMASS: CHALLENGES AND IMPLICATIONS

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Abstract

Technological developments in biomass harvesting peaked in the early to mid-seventies. Harvest operations in natural stands often included the removal of biomass material with conventional products like pulpwood and sawlogs. Since that time, forest management philosophies have changed dramatically, emphasizing partial harvests and thinnings over clearcut harvests. This change has, in turn, affected the type of equipment used for harvesting. The emphasis on leaving slash and debris on site, rather than remove it as a potential biomass product, has further affected the ability to effectively harvest biomass material from our forests.

Newly developed logging systems, called cut-to-length systems, were introduced from Scandinavia in the mid-eighties and produced a minor revolution in our forests. The design of these systems emphasized stand and site protection over high production and low costs. Biomass production has diminished as a priority of harvesting system design to a point where the cost of producing a ton of biomass may well exceed its market value.

Harvest system studies summarized in this report suggest that these newer systems do protect the forest environment, but at a cost to biomass and conventional production. Overall, the cost to produce conventional sawlogs and pulpwood may have increased by 40 to 50 percent using these newer systems. Biomass, typically produced at a smaller profit margin than conventional material, may have increased in cost even more than 50 percent. Even conventional systems cost 20 to 30 percent more to operate in the partial harvests commonly prescribed on our forests.

In contrast, the value of biomass has not increased at the same rate as conventional products. Competing energy sources have affected the demand for energy wood and chips that were marketed only as fuel in the past, are now being sought for engineered wood products at a higher price.

Current trends do not favor biomass production in many areas of North America. Machine design is not addressing biomass production, nor are logging contractors considering biomass as a lucrative market. These philosophies will change only if the price of conventional energy products increase as they did in the seventies.

Introduction

Biomass for energy production is available from many sources, although a major source of biomass has traditionally been obtained through the harvest of natural stands of timber. Biomass harvesting produces fuel chips from woody biomass in conjunction with more conventional products like sawlogs and pulpwood, typically as part of a clearcut harvest.

Clearcutting, where all commercial timber is removed from a stand during harvest, has become less popular due to public concern over visual impacts and a greater emphasis on ecosystem management within our forests. On many National Forests, the use of clearcutting as a management tool is limited, being replaced with partial harvests. These shifts in forest management have severely curtailed the amount of available wood residue for biomass production.

However, new opportunities are becoming available for biomass production from natural forest residues, particularly in western forests. Many interior forests from Washington to California face disaster either from fire, insect attack, disease, or over-stocking. Massive forest fires have brought these problems to the attention of the public, who have encouraged change.

One of the most popular management 'fixes" for overstocked stands with high fire risk or poor stand health is thinning. Thinnings remove merchantable and sub-merchantable trees from the stand to reduce fuel loads, improve growing conditions, and remove undesirable trees from the stand. Commercial thinnings remove enough material from the stand to provide a return to the landowner and the contractor, while maintaining or improving stand and site quality.

Commercial thinning has gained substantial popularity within recent years, due primarily to the increased value of lumber in the western United States. On many National Forests managed by the U.S. Forest Service and the Bureau of Land Management (BLM), commercial thinning is the primary management tool for improving stand conditions and provides most, if not all, of the timber harvested from these forests. The sub-merchantable volumes removed during a commercial thinning could be converted to biomass chips under the right circumstances.

From another perspective, forest management approaches have changed relative to wood residues. While early biomass harvesting operations emphasized complete removal of the woody component of the forest, the current focus of management is retention and dispersal of the woody debris and slash, while removing only the bole wood for raw material (Watson and Stokes, 1984). Concerns over lost nutrients and slash concentrations at the landing or roadside have encouraged a greater emphasis on leaving a large portion of the branches and tops in the forest, thereby reducing the amount of material available for biomass products.

Management has also attempted to reduce the area left in heavily traveled roads and trails on thinned sites. Systems that require large landings, like most chipping operations, have been excluded from many thinning harvests in favor of those systems that can reduce soil compaction, minimize road and trail construction, and improve slash dispersal throughout the stand. This is a particular concern for thinning operations where the stand may require two or even three entries prior to any type of final harvest. If operations were used that required 15 to 20 percent of the stand area for trails and roads at each harvest entry, subsequent timber production would be seriously jeopardized on the site, simply due to the large area left to non-productive trails and roads.

Soil compaction, which reduces tree growth and development, was less of a problem on clearcuts, where the site could be rehabilitated before planting. Machines commonly used on clearcuts often produced ground pressure levels exceeding 12 to 15 psi when loaded. In contrast, most newly developed thinning machines use three and four axle carriers or tracks to minimize ground pressure and reduce soil compaction problems.

The situation facing biomass producers has changed. The type of harvest used to manage stands, combined with the changing attitudes of forest managers about slash dispersal, area in trails, and soil compaction affect whether biomass harvesting can be conducted. As harvesting technology changes, will these newly developed machines be able to provide biomass material at competitive rates? Will these new systems, or even the older, more conventional systems, be able to adequately harvest biomass economically when conducting partial harvests or thinnings?

Machine Development

Harvesting machine development has progressed at a rapid pace over the past thirty-five years. However, the initial series of developments in machine design were perhaps the most critical for the introduction of biomass harvesting.

The first machines introduced in the woods that had an impact on biomass production were the feller-buncher and grapple skidder. This two-machine system provided rapid harvesting and transport of entire stems to a central location, such as the landing. The system was highly productive, providing material for processing at rates ranging to 250 tons of wood or more per day. Biomass, in the form of tops and branches and small stems, was provided as a result of the harvesting process. A second and slightly later innovation, the in-woods chipper, further enhanced the potential for biomass production. With the introduction of these three machines, biomass chip production was possible on a large scale.

Over time, these machines were modified to incorporate a number of new features. Specifically, rubber tired feller-bunchers and skidders were modified to incorporate wider tires that would help to minimize soil compaction and rutting. Production capacities were increased to improve performance and lower the cost of production. Chipper infeed size and horsepower characteristics were increased to improve performance and allow the machines to chip hardwood and other dense species. Generally, the harvest system that evolved was capable of producing large volumes of pulp and biomass chips, as well as conventional roundwood products.

Because these systems were very capital intensive, costing up to several million dollars, contractors were required to harvest large acreages using clearcut techniques. In addition, the equipment was designed primarily for high production. Feller-bunchers were designed that could fell and bunch over sixty trees per hour. Large capacity skidders capable of skidding over five tons at a time were common. Chippers were capable of handling large diameter cull logs and could chip almost any species, regardless of density.

These operations left very little biomass on site to provide nutrients for subsequent regeneration. Large segments of the harvested site were placed in non-productive skid trails, roads, and landings. Generally, sites harvested for conventional and biomass products were subjected to fairly extensive damage through harvest operations.

As noted previously, various social and scientific pressures have changed many of our traditional approaches to managing the forest. In turn, the operational parameters associated with harvesting systems used for stand manipulation were modified. Machines were required that minimized soil disturbance and compaction, rutting, and stand damage. Managers wanted lower trail concentrations and narrow corridors where partial harvests were conducted to reduce the visual impact of any harvest entry. Woody debris within the forest was desirable, particularly if the material could be treated so that decomposition would occur more rapidly.

Few, if any, traditional harvesting systems used on clearcuts could achieve these goals. Feller-bunchers were designed to handle a variety of tree sizes and were built to avoid tip-over during the felling phase. Their width occasionally reached 16 feet, far exceeding the limits desired by most forest managers during a partial harvest. Skidders were large with wide tires to avoid rutting. They carried heavy loads by dragging or skidding the material, disturbing the soil in and around the created skid trail. Trees brought to the landing or roadside were processed at a central location where large piles of slash accumulated. Chipping operations required large areas where the wood could be piled and chipped. These landings were often heavily compacted and difficult to rehabilitate.

At the same time, biomass was becoming a less valuable product, since inroads in demand and subsequent production, had been made by developing alternative biomass markets. And by the mid-eighties the fuel crisis was a long forgotten event. Many public utilities found the prospect of dealing with woody biomass far less desirable than dealing with fuel sources like hydroelectric power and natural gas (Twaddle et al, 1989). Competition for the produced chips also increased because of their expanded use as the raw material in engineered wood products.

Shifts in forest management, from clearcuts to thinnings, had an obvious effect on machine development. Scandinavian harvesting systems became popular because they offered the characteristics demanded for machine operation in partial harvests (Baumgras, 1986). Three and four axle machines became standard carriers for these systems, allowing greater machine weight distribution and less soil compaction. Boom-mounted harvesters minimized machine traffic during the felling and processing phases. Boom length was gradually lengthened to further reduce the amount of traffic required in the stand. Harvester heads were designed so that slash (limbs and tops) could be removed at the stump. Single-grip harvester heads improved on this concept by allowing the operator to process a tree directly in front of the harvester that provided a cushion of limbs for the machine to travel on. Forwarders were designed to follow on these cushioned paths, picking up the short logs (<20 feet in length) and placing them in a bunk mounted on the forwarder. The forwarder was designed to carry the logs, rather than skid them, to further reduce logging impact on the site.

For steeper slopes, self-leveling tracked carriers were developed that could harvest trees without adversely affecting the site. These machines, originally equipped with feller-buncher heads, were soon modified to carry the single-grip harvester head that processes the tree in the forest. Combining these machines with conventional three-axle forwarders allowed some harvest to take place on steeper slopes common in the northwestern United States.

The advances in forest harvesting technology have not extended to cable-based systems. While machines designed to harvest trees from steep slopes over 35 percent have been available for many years, most of these systems have remained the same over the years. Cable systems are highly labor intensive, typically requiring between four and six laborers to fell and yard logs to the landing.

As thinning becomes a larger component of forest management on steep slopes, yarding systems designed to handle the smaller stems associated with thinning harvests are being developed. Small skylines designed primarily for thinning are available from a number of companies for thinning operations (McNeel et al, 1991). However, these systems are expensive to use and provide low productivity relative to most ground-based systems. Typical production from a cable thinning operation will range from 25 tons to 100 tons per day and the cost of production is often twice the cost of production from a conventional ground-based system.

One development that might prove useful for biomass production is the monocable system studied by Moroto and Fujiwara (1979) in the mountains of Japan. The system is designed as a continuous loop of small diameter cable run through tree-jacks mounted about four feet above the ground, powered by a small winch system. The system is used primarily for pre-commercial thinning of small diameter stems. Cable size is typically 0.25 inches in diameter and the harvested stems are generally of a size that one laborer can lift one end of the stem up, choke it using a hemp or twine rope, and attach the choked stem to the monocable. This system is used primarily for pre-commercial thinning, although some effort is being made to adapt the yarder for commercial thinning operations. A major failing of the yarder is low productivity, since piece size is very small, and the operation is very labor intensive.

Harvesting System Studies

The shift to partial harvests combined with the need to minimize site impacts have dramatically affected harvest operations in North America. Biomass can still be harvested with these systems, but can it be harvested in an efficient manner? Several studies have recently been conducted in the western United States examining topics like productivity and/or costs associated with partial harvests using both conventional systems and the harvester-forwarder system. Review of these research findings indicate that harvester-forwarders do minimize the effect of harvesting on the site and stand. They also suggest that these systems, designed primarily for safe operation in partial harvests, are not as cost effective as past systems in producing biomass from clearcut harvests. There are, however, problems associated with using even conventional systems for biomass harvests.

Holmsen (1991) examined the productivity and costs of using a conventional harvesting system for thinning an interior lodgepole pine (*Pinus contorta*) stand in British Columbia. The operation included manual felling and processing, and skidding with a small crawler-tractor. Costs were estimated to be 24 percent higher than those for clearcutting with similar equipment in this type of stand, suggesting that even when using conventional equipment, thinning harvests will typically be more costly. A similar study by Bennett (1993), who evaluated manual felling/processing and crawler skidding for a partial harvest in second-growth, coastal Douglas-fir (*Pseudotsuga menzissii*), concluded that harvesting costs with this conventional system averaged between 20 and 30 percent more than a conventional clearcut harvest with similar equipment.

Andersson (1994), in a study comparing cut-to-length and tree-length systems, found that cut-to-length systems using a single-grip harvester and an 11 ton capacity forwarder were able to extract more fiber from the forest than tree-length systems using a feller-buncher, grapple skidder, and roadside stroke delimber. The study found that cut-to-length systems are capable of capturing downed wood that would normally be left by the tree-length system.

However, processing this downed wood did not lead to lower harvest costs. In fact, by processing the smaller stems that have succumbed to mortality, the cut-to-length system actually increased harvesting costs per cubic meter. A cost comparison of the two systems using productivity data obtained during field studies suggests that, for this study, the tree-length system was able to lower the cost of wood delivered to roadside by almost one dollar (Cdn) per cubic meter.

Barbour and others (1995) compared harvester performance when thinning small diameter stands of timber in eastern Washington and found significant differences in performance based on average stand diameter. The study found that a shift in mean stand diameter from 9.8 inches at DBH (diameter at breast height) to 8.2 inches at DBH increased the average felling and processing costs for the harvester by more than 100 percent (Fig. 1). These findings suggest that harvester performance in small diameter stands is not very cost effective. And, as most biomass harvest operations handle small diameter material, these findings suggest that the cut-to-length system may prove too expensive for biomass production.

Hartsough and others (1994) evaluated three systems for thinning pine plantations and natural stands in California. The products from these operations were limited to sawlogs and biomass fuel chips. The whole tree system consisted of a self-leveling feller-buncher equipped with a shear, a grapple skidder, a loader, and a chipper. The cut-to-length system consisted of a single-grip harvester, a forwarder, loader, and a chipper. The last system, called a hybrid system, consisted of a self-leveling feller-buncher/harvester, a grapple skidder, loader, and chipper.

Productivity was estimated through field observation and the costs for delivering the wood from stump to mill were computed in both the plantation and natural stands (Fig. 2). Generally, the stump-to-mill biomass fuel chip costs associated with the cut-to-length system were highest in both the plantation and the natural stand, averaging $66.20 per bone-dry ton (BDT) in the natural stand and $48.20 per BDT in the plantation. In contrast, the whole tree system averaged $33.50 per BDT in the natural stand and $30.10 per BDT in the plantation.

Stand damage levels were also measured for the three systems. In the natural stands, the cut-to-length system produced the least damage, causing approximately 10 percent damage in the residual stand. The hybrid and whole tree systems produced 15 and 13 percent damage, respectively. None of the observed differences were determined to be significantly different.

McNeel and Ballard (1992) found that trail and road concentration for a thinning operation with a cut-to-length system in a Douglas-fir plantation averaged less than 15 percent of the total harvested area. In addition, heavily traveled roads and trails comprised less than seven percent of the total area. No large landings were used during the harvest, since the harvested wood was decked at the roadside. Other studies, notably by Froehlich (1973), Siren (1989), and Steinbrenner and Gessel (1955), indicated substantially higher levels of trail and road concentration for conventional systems, ranging from 25 to 30 percent of the total productive forest area.

Lanford and Stokes (1995) compared a conventional feller-buncher, grapple skidder, loader/slasher system with a harvester-forwarder (cut-to-length) system to determine relative effects on the stand and site after thinning. Residual stand damage was greater for the conventional system, averaging 25 scarred trees per acre versus only 10 trees per acre for the cut-to-length system. Soil disturbance and compaction were found to be greater on the sites thinned with the conventional system when compared with sites thinned using the cut-to-length system.

Discussion and Conclusions

Biomass harvesting operations have traditionally used large capacity logging equipment designed for use on clearcuts. The high ownership and operating costs associated with these machines required logging contractors to emphasize high production using even-age management, specifically clearcut harvesting. These harvesting operations took nearly all of the above-ground woody material and created sites that were easily prepared for later planting efforts. These systems became well established after oil prices peaked in the early seventies.

Since then, the need for biomass fuels has gradually declined. Forest management concerns have shifted and the techniques used to manage forest stands have been modified to emphasize partial harvesting operations. More important, the systems used for harvesting have changed. Many logging contractors now use cut-to-length systems that process the harvested trees in the forest, rather than at the landing. These systems are also very sensitive to harvested tree size, since the processing operation deals with one stem at a time.

Review of machine development over the last twenty years indicates that little attention has been given to biomass harvesting. Greater effort has been made to reduce the impact of the harvesting system on the stand and site. Emphasis has been placed on the development of machines to conduct partial harvests, rather than clearcuts. Resulting machines are compact, maneuverable, and "environmentally friendly".

However, these machines are not designed to harvest biomass. They remove the limbs and tops at the stump. The product being moved to the roadside or landing is no longer in whole tree form, but rather in the form of logs that can be carried in a forwarder bunk. Felling and processing is relatively slow when compared with conventional whole tree systems, and the machines are very sensitive to stem volume. As a result, smaller trees cost substantially more to process than larger trees with these newer systems.

Harvest studies support the hypothesis that newly developed systems have been designed that sacrifice productivity and low cost operations for better protection of the stand and site. Some newly designed equipment, like the self-leveling feller-buncher, could have a positive impact on biomass production. However, this machine provides little innovation beyond the ability to mechanically fell trees on steep slopes. Forwarding or skidding the biomass off these slopes is still difficult and costly.

Where are we relative to biomass harvesting at the turn of the twenty-first century? Actually, many new logging operations are less capable of harvesting biomass than the systems used in the early seventies. Until the focus of production shifts again to biomass removal, we can only expect further advances in designs that will reduce stand and site impacts - at a higher cost of production. The technology exists, and has existed for many years, to effectively harvest biomass in a cost effective manner. This technology still exists, but is not widely used.

Biomass producers currently have two options. They can either use equipment that was designed nearly twenty years to effectively harvest biomass material. Or they can use these newly designed machines, like the harvester and forwarder, to remove small volumes of biomass at a higher cost than ever reported before.

The forest industry and the forestry equipment sector have essentially abandoned forest biomass production in favor of environmental protection. Until biomass prices increase enough to offset the higher production costs associated with environmentally friendly cut-to-length systems, this trend will continue.

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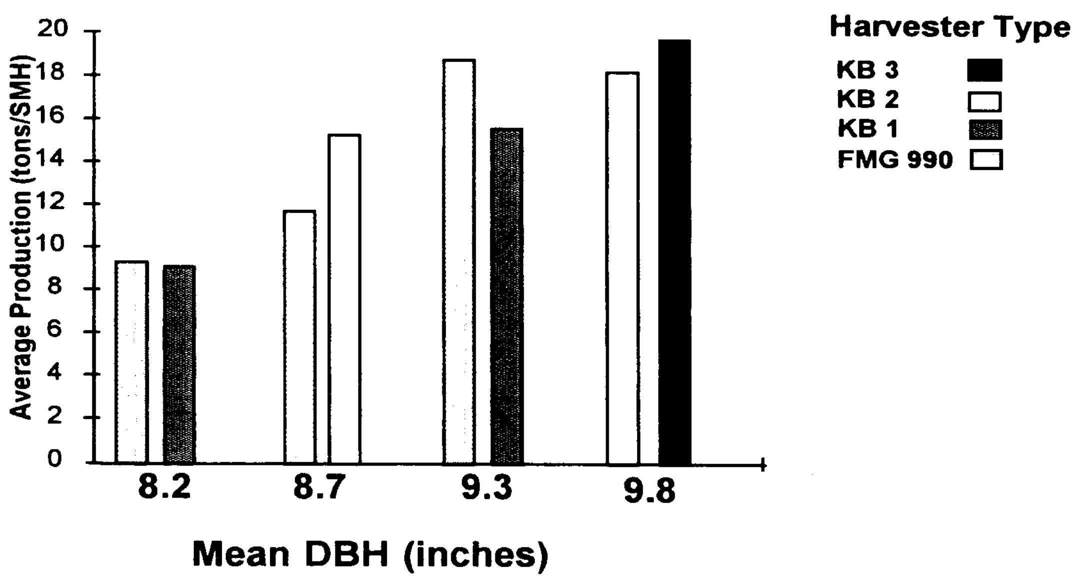

Figure 1: Comparison of felling and processing costs for harvester operations in a mixed stand in eastern Washington (From Barbour et al., 1995).

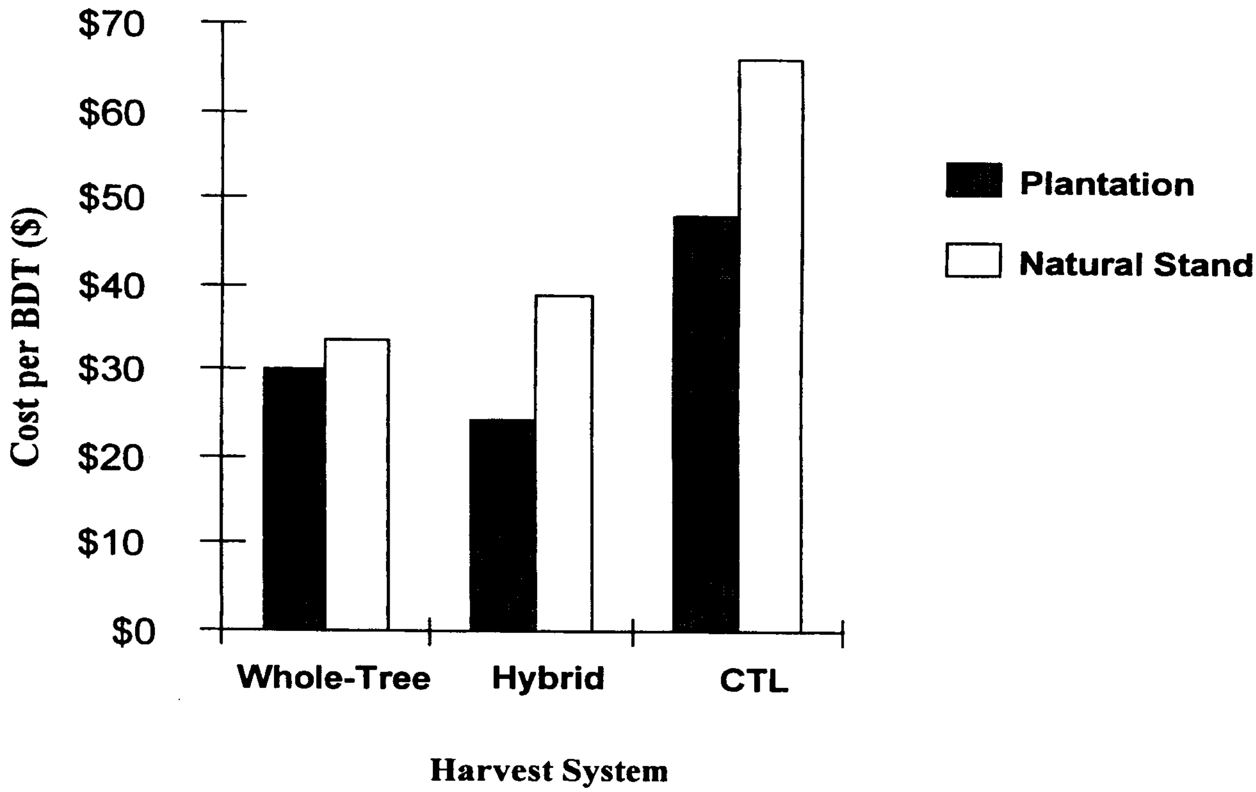

Figure 2: Comparison of stump-to-mill costs for three different harvesting systems thinning ponderosa pine stands in northern California (From Hartsough et al., 1994).

RESOURCE POTENTIAL OF WOOD-BASED WASTES IN THE UNITED STATES

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Abstract

Large amounts of waste are generated in the United States annually. Although much of this material is indeed waste, an increasing share is becoming a valuable resource. Wood is usually thought of as a renewable, not a recyclable, resource. However, solid residues from primary timber processing facilities have been recycled into usable products for decades. Wooden pallets are recycled into new pallets or other wood products at an increasing rate, and wood waste from construction and demolition sites is becoming an important commodity. Wood from urban waste collection may too prove to be a valuable resource. The first step in developing waste wood into a viable resource is to quantify the amounts of waste wood available by source and type of material. There are three major sources of wood waste in the United States—municipal solid waste (MSW), new construction and demolition waste, and wood residues from primary timber manufacturing facilities. Included in MSW are pallets and yard waste. In this report, total amounts of waste generated, amounts of wood waste generated by type, and amounts of wood waste potentially available for recycling are quantified for each source of waste. Estimates are based on published waste generation volumes and rates, measures of economic activity, and trends in virgin wood use in specific markets. The report also identifies possible uses for each source of wood waste and includes recommendations for better utilizing this resource.

Introduction

Large amounts of waste are generated in the United States annually. Although much of this material is indeed waste, an increasing share is now a valuable resource. In the past, recycling was limited to a few commodity items such as metal, glass, and old newspapers. Today, such diverse items as plastic containers and film, used oil and oil filters, fluorescent lighting tubes, and aerosol spray cans are being recycled.

Solid wood, usually not included on any of these lists, should appear in all three. Wood residues from primary timber processing facilities have been recycled into usable products for decades. Wooden pallets are recycled into new pallets or other wood products at an increasing rate, and wood waste from construction and demolition sites is becoming an important commodity. Urban wood waste may soon be a valuable resource. The first step in developing solid wood waste into a viable resource is to quantify the amounts of wood waste available by source and type of material. There are three major sources of wood waste in the United States—municipal solid waste, new construction and demolition waste, and wood residues from primary timber manufacturing facilities. The purpose of this report is to estimate total amounts of waste generated, amounts of wood waste by type, and amounts of wood waste potentially recoverable by source of material. Wood waste from other, lesser sources are identified but not included in this analysis, nor are residues left in the woods from logging or cultural operations and other nonwood agricultural wastes. Also, it should be noted that this report deals exclusively with solid wood waste. Wood fiber used for paper and paperboard is not included.

Municipal Solid Waste

Municipal solid waste (MSW) is waste from residential, commercial, institutional and industrial sources. It includes waste such as durable goods, nondurable goods, containers and packaging, food scraps, yard trimmings, and miscellaneous inorganic waste (14). Specific examples of MSW are appliances, automobile tires, newspapers, clothing, boxes, disposable tableware, office and classroom paper, wooden pallets, and cafeteria waste. MSW does not include waste from other sources, such as construction and demolition waste, automobiles, municipal sludge, combustion ash, and industrial process wastes that may, or may not, be disposed of in municipal waste landfills or incinerators.

An estimated 188 million metric tonnes ($\times 10^6$ t) (207 million short tons [$\times 10^6$ tons]) of MSW were generated in the United States in 1993 (14) (Fig. 1). Since 1960 (with the exception of 1991), MSW generation has increased steadily from 80×10^6 t (88 tons). MSW generation is sensitive to overall economic conditions. Periods of economic recession—either severe, or mild as in 1991—cause deviations of MSW from long-term trends. Between 1960 and 1993, MSW generation increased at an average annual rate of 2.6% per year. Since 1990, the rate has been just 1.5% per year compared to 2.8% per year for the period 1960 through 1990. Overall, MSW is projected to be 198×10^6 t (218×10^6 tons) by the year 2000. This represents an average annual increase of just 0.7% per year from 1993 through 2000. Thus, although total MSW is increasing, it is increasing at a decreasing rate, and is expected to do so into the foreseeable future. Per capita MSW generation averaged 1.99 kg (4.39 lb) per person per day in 1993, an increase from 1.97 kg (4.35 lb) in 1990 and 1.21 kg (2.66 lb) in 1960. Trends in per capita generation closely followed total MSW generation from 1960 through 1990. Source reduction and recycling programs initiated in the late 1980s began to influence waste generation by 1990. Per capita generation began to plateau in the early 1990s; in 2000, it is expected to decrease (to 1.96 kg [4.32 lb]), for the first time since 1960.

A wide variety of products are included in the overall MSW generation figures. The wood waste and yard trimmings portion of MSW is examined here. Wood waste includes such items as wooden furniture and cabinets, pallets and containers, scrap lumber and panels from other than new construction or demolition activities, and wood waste from manufacturing facilities. Wood waste does not include roundwood or unprocessed wood. Yard trimmings include leaves and grass clippings, brush, and tree trimmings and removals. The amounts and types generated, currently recovered for recycling, composting, or combustion, and discarded determine the physical supply of solid wood waste that may be available for recovery from the municipal waste stream.

Wood

In 1993, 12.4×10^6 t (13.7×10^6 tons) of MSW wood waste was generated in the United States (14) (Table 1), nearly 7% of all MSW. Of this, 1.2×10^6 t (1.3×10^6 tons) was recovered for recycling or composting, and the rest was discarded. The discarded wood waste was sent to either combustion facilities or landfills. The exact proportion of discards that were combusted is available only for overall MSW, not for specific materials within the waste stream. Approximately 95% of all MSW combustion facilities burn either unprocessed mixed waste or processed mixed waste (refuse-derived fuel). In 1993, about 30.0×10^6 t (33.1×10^6 tons) of MSW was burned. Since wood waste accounts for about 10% of all combustible mixed MSW, about 3.0×10^6 t (3.3×10^6 tons) was burned in 1993. Also, some discarded wood waste was too contaminated, commingled with other waste, or otherwise unacceptable for recovery. Overall, about 60% of all discarded wood waste 6.7×10^6 t (7.4×10^6 tons) was considered to be recoverable in 1993 (2,3).

Yard Trimmings

Yard trimmings constituted the second largest single component of MSW in 1993 at 29.8×10^6 t (32.8×10^6 tons), or nearly 16% of all MSW (14). Of this, 5.9×10^6 t (6.5×10^6 tons) was recovered for recycling or composting, and the remainder (23.9×10^6 t [26.3×10^6 tons]) was discarded. A recent study detailed the generation and disposition of all urban tree and landscape residues, not just the proportion in the municipal waste stream (8). In 1993, 95% of all urban tree and landscape residues, by volume, was woody residues.

Table 1. Wood Waste Generated and Recoverable From Various Sources

Source	Generated 10^6 t	Generated (10^6 tons)	Recoverable 10^6 t	Recoverable (10^6 tons)	%
Municipal solid waste					
Wood waste	12.4	(13.7)	6.7	(7.4)	54
Woody yard trimmings	28.2	(31.1)	13.6	(15.1)	48
Total	40.6	(44.8)	20.3	(22.5)	50
Construction & demolition					
New construction waste	6.1	(6.7)	5.4	(5.9)	88
Demolition waste	22.7	(25.0)	6.8	(7.5)	30
Total	28.8	(31.7)	12.2	(13.4)	42
Primary timber processing					
Bark residues	26.0	(28.7)	1.4	(1.5)	5
Wood residues	74.5	(82.1)	4.3	(4.7)	6
Total	100.5	(110.8)	5.7	(6.2)	6
Total wood waste	169.9	(187.3)	38.2	(42.1)	22

Therefore, about 28.2×10^6 t (31.1×10^6 tons) of woody residue was generated in MSW in 1993; 22.7×10^6 t (25.0×10^6 tons) was discarded. After combustion and allowance for unrecoverable material due to contamination, size, commingling with other materials, and cost of collection, about 13.6×10^6 t (15.0×10^6 tons) were considered to be available for recovery (60% of the total amount discarded (2,3)) (Table 1).

Total Solid Wood Waste

In 1993, half of all solid wood waste in MSW, or about 20.3×10^6 t (22.5×10^6 tons), was potentially recoverable (Table 1). It should be emphasized that although these amounts were deemed potentially available, many factors affect recoverability and usability, such as the size and condition of the material, extent of commingling with other types of waste, contamination and physical location of the material, and costs associated with acquiring, transporting, and processing the material into a useable raw material. Overall economic conditions and changing recycling rates will affect future supplies. Estimates of recoverable solid wood waste for 1993 are practical limits to overall supply given current recovery technology and costs, not exact amounts that were specifically available.

New Construction and Demolition Waste

New construction and demolition wastes are not a single form of waste, as often thought. These wastes originate from distinctly different sources, have different characteristics, and differ in their ease of separation, recoverability, and recyclability. New construction waste, particularly wood waste, originates from the construction, repair, and remodeling of single- and multifamily houses, and the construction of low-rise nonresidential buildings. Demolition waste originates at any site where a building or other structure is being demolished. New construction waste tends to be much cleaner than demolition waste and consists of contemporary types of materials; demolition waste is usually more contaminated with foreign materials such as paints, fasteners, wall covering materials, and insulation, and typically contains a more diverse mix of materials. Many materials in demolition waste are no longer being widely used in new construction, which makes them potentially more difficult to recycle. New construction waste can be readily separated on the job site with little additional effort by the builder, whereas source separation of waste at the demolition site can be very time-consuming and costly. Demolition practices would have to be radically altered to achieve adequate source separation. For these reasons, new construction and demolition wastes were evaluated separately.

Although construction and demolition (C&D) waste recovery is increasing, little consistent information is available nationally for developing overall estimates of materials generation and recovery. Available data are limited to specific case studies that may or may not reflect overall national trends and vary widely. The C&D waste generation rates published in the past 25 years ranged from a low of 0.05 kg (0.12 lb) per person/day (19.9 kg [43.8 lb] per year) to 1.60 kg (3.52 lb) per person/day (582.6 kg [1,284.4 lb] per year) (11). Factors that affect C&D generation rates include new construction activity, type of structure, type of materials, demolition activity, type and age of structure being demolished, and extent to which materials are removed from structures for reuse or recycling prior to demolition. Because of variability in reported C&D waste generation rates and the many factors that affect them, information from specific case studies that could be linked to national levels of construction activity was used to estimate C&D waste generation in 1993. The resulting estimates, although not precise estimates of the size or extent of this waste stream, particularly regionally or locally, provide a good, overall view of the C&D waste resource.

New Construction Waste

New residential and nonresidential buildings, as well as nonbuilding construction, generates large amounts of waste annually. Information on the types and amounts of waste generated is sketchy and limited to anecdotes or a handful of case studies. Since nearly all new single-family and low-rise multifamily residential structures are based on traditional wood-frame building technology, information on this type of construction was used to develop estimates of wood waste generated and recoverable for new construction. Specific waste generation rates were obtained from a case study of the Portland, Oregon, metropolitan area (5). Although specific to the structures examined, the waste generation rates were typical of all new residential construction in 1993 because the individual structures examined had characteristics typical of all new residential construction. Information from this source was used to develop weighted average waste generation rates based on floor area built for new single-family and multifamily houses. These rates were then applied to total floor area of each type of structure built in the United States in 1993 to develop estimates of total waste generated for residential construction. Estimates were then adjusted to account for new nonresidential construction and residential repair/remodeling. Waste from the production of mobile homes and manufactured housing was not included since it is a component of MSW.

An estimated 2,237 kg (4,931 lb) of solid wood waste, and 1,215 kg (2,678 lb) of paper and other waste were generated for the average 188.3 m^2 (2,027 ft^2) single-family house built in the Portland metropolitan area in 1993 (5). Wood waste was generated at 11.86 kg/m^2 (2.43 lb/ft^2) of finished floor area. Overall, an estimated 88% of the wood waste was considered to be recoverable. New multifamily construction generated 619 kg (1,365 lb) of wood waste and 390 kg (860 lb) of other waste per living (apartment) unit. These amounts included not only materials generated per unit, but also prorated amounts for common areas like laundry rooms, lobbies, and recreational areas. Wood waste was generated at a rate of 7.42 kg/m^2 (1.52 lb/ft^2) of finished floor area; 88% of this material was also recoverable.

In 1993, 1,126,000 new single-family houses with an average 195 m^2 (2,095 ft^2) of floor area and 153,000 multifamily living units with an average 99 m^2 (1,065 ft^2) of floor area were built nationally (12). Applying the average wood waste generation rates per unit of floor area (5) resulted in an estimated 2.6×10^6 t (2.9×10^6 tons) of wood waste generated in 1993 for new single-family construction and 0.1×10^6 t (0.1×10^6 tons) for new multifamily construction (Fig. 2). Based on materials use factors (building material required per unit of finished floor area) for new residential construction (1,7), an estimated 27.1×10^6 t (29.9×10^6 tons) of wood products was required in 1993 for all new residential construction. Wood waste was about 10% of the wood used to build the structures.

Large amounts of wood products are required for residential repair and remodeling, and new nonresidential construction annually, and these activities therefore generate large amounts of wood waste. Reliable information on the amounts of waste generated by these types of construction was not available. However, the types of materials and construction techniques typically used for residential repair and remodeling are used for new single-family construction as well. Therefore, waste generation estimates for residential repair and remodeling were based on waste generation rates for new single-family construction. Data on wood products use in 1991 for residential repair and remodeling (6) were updated to 1993 using expenditures data (13). Total wood products use was estimated to be 25.8×10^6 t (28.4×10^6 tons) and wood waste generated about 2.6×10^3 t (2.9×10^6 tons) in 1993 by residential repair and remodeling activities (Fig. 2).

Estimates of amounts of wood products used for new nonresidential construction in 1986 were used to estimate that used in 1993 (9). In 1993, about 8.6×10^6 t (9.5×10^6 tons) of wood products was used for new nonresidential construction and one-third of that used for new single-family construction (Fig. 2). The wood products and construction techniques typically used to build low-rise, light-frame nonresidential buildings such as stores and office buildings are similar to that used for new residential construction. Waste generation is also expected to be similar. Wood is not typically used as the primary construction material for larger nonresidential projects such as warehouses, high-rise buildings, and highways, and the building techniques are different. Information needed to estimate waste from such building activities was not available. However, since wood is not the primary building material for these larger nonresidential projects, total waste wood generation should not be greatly affected. In 1993, the combined use of wood products for residential repair/remodeling, and new nonresidential construction was about 27% greater than that for new residential construction (single-family and multifamily combined) and generated 25% more wood waste.

Wood waste generation for all new construction (new single- and multifamily residential, residential repair and remodeling, and new nonresidential) was estimated to be 6.1×10^6 t (6.7×10^6 tons) in 1993, with 5.4×10^6 t (5.9×10^6 tons) recoverable (Table 1). The percentage of new residential construction waste considered to be recoverable was used to estimate recoverable amounts of wood waste from residential repair and remodeling, and new nonresidential construction.

Demolition Waste

Demolition waste is the heterogeneous mixture of building materials generated by demolishing a building or other structure. It typically contains aggregate, concrete, wood, paper, metal, insulation, glass, and other contemporary building materials. Depending on the age and type of structure, it may also contain asbestos, lead-based finishes, mercury, polychlorinated biphenyl compounds (PCBs) or other contaminates. Estimates on the amounts of demolition waste generated have been made over the years. These estimates are usually for specific localities, typically include new construction waste, and are based on the size of the resident population. (Urban areas tend to generate more C&D waste per capita than suburban or rural areas.) The C&D waste generation rates were estimated by the California Waste Management Board and the New York Solid Waste Management Board for 1968 and 1991, respectively (11) (Fig. 3). Because of the consistency between the New York and California rates, and the relationship between population and waste generation, the New York C&D generation rates were used to estimate demolition waste generated in the United States in 1993.

To estimate demolition waste, total C&D waste was first estimated by annualizing the generation rates from the 1991 New York study and multiplying them by the size of the population living in metropolitan and nonmetropolitan statistical areas. The estimated amount of new construction waste was then subtracted, resulting in an estimated 43.8×10^6 t (48.3×10^6 tons) of demolition waste generated in 1993. Finally, information from a 1991 Metropolitan Toronto Waste Composition Study indicated that 52% of demolition waste being disposed of in metropolitan Toronto landfills was wood, and 48% was other materials (11). Application of these percentages resulted in an estimated 22.7×10^6 t (25.0×10^6 tons) of wood in demolition waste in the United States in 1993.

Recoverability of demolition waste is difficult to determine. The characteristics of demolition waste make it more difficult to recover and recycle than construction waste. Recycling operations are very sensitive to contamination. Entire loads of demolition waste are typically rejected if contaminated. About 15% of the wood, by weight (38% by volume), received at a Massachusetts demolition waste recycling facility is usable (4). These figures are for a specific operation producing a single product and are based on primary crushing of the incoming demolition waste to achieve uniform material size. Differences in treatment technology, products manufactured, and source of demolition waste affect the utilization rate. Based on an assumed overall 30% utilization rate, approximately 6.8×10^6 t (7.5×10^6 tons) of wood demolition waste was estimated to be recoverable in 1993 (Table 1).

Primary Timber Processing Mill Residues

Primary timber processing facilities in the United States generate large amounts of residues in such forms as bark, sawmill slabs and edging, sawdust, and peeler log cores. In 1991, an estimated 26.0 $\times 10^6$ dry t (28.7 $\times 10^6$ tons) of bark and 74.5 $\times 10^6$ dry t (82.1 $\times 10^6$ tons) of wood residues were generated (Table 1) (10). Many mill residues are being used to produce other products, primarily fiber products, nonstructural panels, and fuel. Only 5% of the bark (1.4 $\times 10^6$ t [1.5 $\times 10^6$ tons]) and 6% of the wood residue (4.3 x 10^6 t [4.7 x 10^6 tons]) were not used in 1991. This unused residue is all potentially recoverable. Overall lumber and plywood production changed little between 1991 and 1993. The 1991 mill residue data were therefore used as an estimate for 1993. As such, an estimated 5.7 $\times 10^6$ t (6.2 $\times 10^6$ tons) of bark and wood residue was available for recovery in 1993 (Table 1).

Other Sources

There are many other sources of waste wood, including chemically treated wood used for railroad crossties, switch ties and bridge timbers, telephone and utility poles, and pier and dock timbers, and untreated wood in the form of logging residues left in the woods, chipped brush and limbs resulting from maintenance of utility right-of-ways, and industrial waste wood outside the MSW stream. Some of this material is being reused, some is being burned, some is being disposed of in hazardous waste landfills, and much is being left on site. Chemical treatments and cost of collection make much of this material difficult to recover. The amounts of wood available from these other sources (with the exception of logging residues) are fairly small compared to that from MSW, C&D waste, and mills. For example, in 1993 a total of 12.3 $\times 10^6$ railroad crossties was replaced. The replacement ties were all treated wood and had an estimated volume of 1.2 $\times 10^6$ m^3 (491 $\times 10^6$ board feet [BF]). Bridge and switch tie replacements constituted an additional 0.1 $\times 10^6$ m^3 (44 $\times 10^6$ BF). The combined volume was equivalent to nearly 0.8 $\times 10^6$ t (0.9 $\times 10^6$ tons) of ties replaced. If half the volume of wood in the removed ties were sound, then less than 0.5 $\times 10^6$ t (0.5 $\times 10^6$ tons) of wood would have been recoverable from all railroad tie replacements. This is approximately 10% of the recoverable wood residue from primary timber processing mills, the smallest of the three major sources of wood waste. Although wood from other sources may become a valuable resource in the future, they were not examined in our estimates because of their smaller volumes or obstacles to recovery.

Conclusions

An estimated 170 $\times 10^6$ t (187 $\times 10^6$ tons) of waste wood were generated in the United States in 1993 from MSW, new construction and demolition (C&D) waste, and primary timber processing facilities. Much of this waste was used to produce new products, was used for fuel, or was not suitable for other uses because of contamination or other physical characteristics. Of the total amount generated, about 38 $\times 10^6$ t (42 $\times 10^6$ tons) or 22% was suitable for recovery. More than half of the recoverable waste wood was from MSW, about one-third from C&D wood waste, and the remainder from primary timber processing mill residues. Many technical and economic obstacles need to be overcome before much of the recoverable wood waste can be recycled. This is nevertheless a valuable resource, and it is playing an ever-increasing role in satisfying the demand for wood-based products. Advances are constantly being made in current utilization and new uses are being found. In the forest products industry, for example, furnish consisting of up to half recycled construction waste, pallets, crating, and other wood waste is being used in a particleboard plant in Eugene, Oregon. Also, funding and siting are underway for a medium-density fiberboard (MDF) plant in Toronto, Canada, that will use urban and industrial wood waste exclusively. Six additional MDF plants of the same company are being considered for large metropolitan areas in the United States and Canada. The USDA Forest Service Recycling Initiative is aimed at developing uses for waste wood and paper, particularly building products for residential construction.

[1] The Forest Products Laboratory is maintained in cooperation with the University of Wisconsin.

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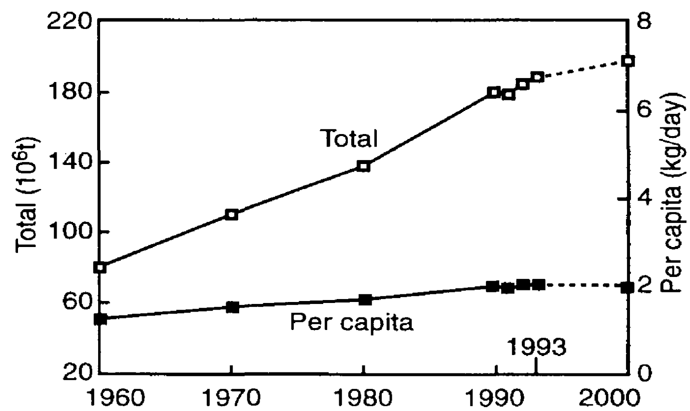

Figure 1. Total and per capita MSW generation, 1993.

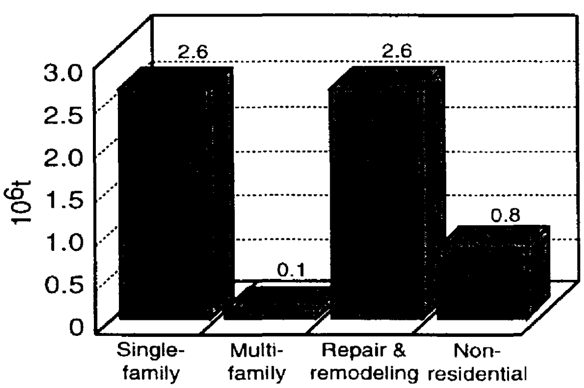

Figure 2. New construction wood waste generation, 1993.

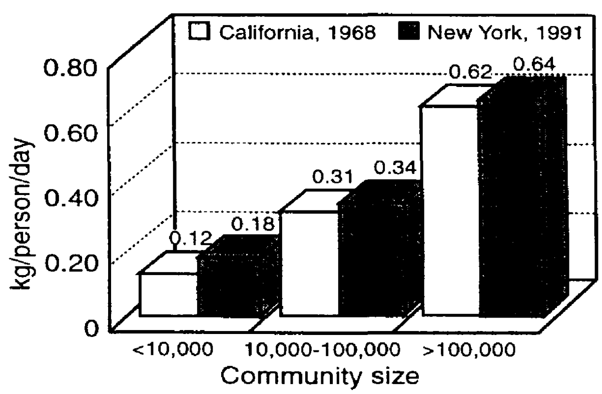

Figure 3. C&D waste generation rates for California and New York.

AN OVERVIEW OF WASTE-TO-ENERGY SYSTEMS IN THE U.S.A.: WASTE AS AN ENERGY SOURCE

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Abstract

This paper examines biomass waste-to-energy in the United States. By far the largest source of biomass fuel is wood and wood wastes which accounts for 80% of biomass energy consumed in the United States. The next largest source is solid waste, which accounts for about 16% of biomass energy consumed. Within this source, municipal, commercial and industrial waste form the largest source of fuel in two ways: a) burned as an actual fuel or processed, i.e. dried, pelletized and then burned, or b) as a producer of methane gas in landfills. The gas is collected and processed to produce either a low to medium Btu fuel or cleaned to obtain pipeline quality natural gas. A few solid waste-to-energy plants are co-firing furnaces with sewage sludge; however, these types of facilities remain the rare exception.

The overall reliance on biomass has increased somewhat over the last decade, particularly with respect to solid waste and wood. Landfill gas recovery is on the increase due to favorable regulations. In contrast, the number of waste-to-energy facilities drawing on waste from the commercial and municipal sectors are not expected to grow in the near future.

Introduction

This paper presents an overview of biomass waste-to-energy in the United States. It will first examine overall production of energy from the municipal, industrial, and agricultural sectors and will then focus more specific remarks on municipal waste-to-energy systems. More specifically, it will highlight trends that have occurred with respect to municipal solid waste-to-energy and methane gas-to-energy occurring at solid waste landfills.

For the purposes of this paper, biomass is defined as a renewable energy source derived from plants, agricultural and industrial residues and processing wastes, municipal solid waste and sewage, and animal wastes. Biomass energy consumption relies on three main feedstocks: Wood; Solid Waste from municipal, commercial, and industrial sectors ; and Alcohol Fuels from corn and other grains. In total, DOE estimates that about 2785 trillion Btus of energy consumed in the United States are derived from biomass. This is an increase of about 22% since 1981.

Wood waste is by far the largest source of biomass fuel. As Figure 1 shows, as of 1992 in terms of trillion Btus, 81% of energy produced from biomass comes from wood. Solid waste is second, contributing 16% of Btus consumed and Alcohol comprises 3%. This contribution by sector has remained somewhat stable over the last fifteen years.

With respect to wood fuel usage, the DOE Energy Information Administration estimates that the industrial sector consumed 71% of the 1593 trillion Btus produced from the burning of waste wood; the residential sector 29%. The high proportion biomass energy supplied by wood is expected to remain stable through the year two thousand and beyond. Its usage is dominated by the paper and lumber industry, which have increased their reliance on this fuel due to growth in output, increase in disposal costs and the desire to more fully use the timber that has been cut.

Figure 2 summarizes the regional distribution of biomass energy consumption across all sources of fuel. On the basis of 2785 trillion Btus of energy produces, the Northeast uses 15%, the South, 49%, the Midwest, 15% and the West, 21%. As can be seen the South is the dominant region in terms of biomass usage. This is due entirely to the high reliance on wood in its industrial paper sector.

If one examines regional usage by type of fuel, other patterns emerge. As shown in Figure 3, the South has the largest usage of wood, due to the strength of the paper industry. The West, with 21% of the wood consumption, reflects the concentration of the lumber industry in this region. With respect to solid waste, there is a more even distribution. The Northeast has the greatest share, 32%; however, the South consumes 28% of this form of energy. Alcohol comprises a very small part of biomass energy use. The greatest level of consumption is in the Midwest, which reports 70% of the total. This is due in large part to the grain processing industries located there.

Solid Waste

Solid Waste according to DOE's biomass energy hierarchy is comprised of industrial, commercial, and residential waste that is ultimately burned to produce energy and landfill wastes that are used to produce methane gas to be used as fuel. In addition, solid waste consists of manufacturing process wastes from a variety of industries. If one looks only at consumption figures for solid waste, than there has been an increase from 88 trillion Btus in 1981 to 457 trillion Btus in 1992. This represents growth of about 400%.This increase can be attributed largely to the growth of municipal waste combustion facilities and methane recovery facilities throughout the country. It is on these two biomass sources that the remainder of this paper will now focus.

Municipal Waste Combustion

The last fifteen years have seen the acceptance municipal waste as a viable biomass fuel. About 17% of the nation's trash is burned and converted to energy as compared to less than 2% in 1980. Nevertheless, the large growth of solid waste as an energy source has peaked in the short run as shown in Table 1. The slowdown in growth is due not as much to problems of technology as to the reluctance of communities to rely on waste-to-energy facilities for a solution to their waste disposal problems. The current legislative and policy environment is not favorable to the reliance on municipal solid waste as a fuel.

Table 1. Status of facility by year

	Year					
Status	1982	1984	1986	1988	1991	1993
Conceptual Planning	15.9%[1] (17)	49.2% (124)	27.9% (75)	37.8% (139)	18.7% (55)	10.9% (27)
Advanced Planning	18.7% (20)	16.3% (41)	26.8% (72)	24.7% (91)	21.1% (62)	8.5% (21)
Operational[2]	55.1% (59)	29.8% (75)	38.3% (103)	30.2% (111)	47.6% (140)	60.5% (150)
Permanent Shutdown	10.3% (11)	4.8% (12)	7.1% (19)	7.3% (27)	12.6% (37)	20.2% (50)
Total %	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**
(Total #)	**(107)**	**(252)**	**(269)**	**(368)**	**(294)**	**(248)**

[1]Percentage of column. [2]Includes projects under construction and temporarily shutdown.

Source: **1993-94 Resource Recovery Yearbook**(New York: GAA, Inc.), 1993.

In absolute numbers, the total number of projects identified more than tripled from 1982 through 1988, with 107 surveyed in 1982 and 368 listed in 1988 (the peak year for WTE in the United States). By 1990, the number of facilities fell to 294 and in 1993, the number of plants identified dropped further to 248. This decrease is the result of a precipitous decline in planned projects and the maturation of existing facilities. Very few new projects are currently in the pipeline. Excluding the 1982 numbers (which may have undercounted planned facilities), the percentage of planned projects ranged from 55% to 65% of the sample through 1988. In 1990, they dropped to 40% of the total and by the end of 1993, this percentage fell to 19%.

There are three main technologies used for waste-to energy: Mass Burn; Modular (Mass Burn); RDF. In addition, there has been some experimentation with pyrolysis and other technologies. Mass burning is the most commonly used process at United States plants. Raw municipal solid waste (MSW) is taken "as is" with little or no shredding or separation prior to combustion. At a few locations sewage sludge is co-fired with the refuse. At most locations, large bulky items such as "white goods", e.g. washing machines, refrigerators, car and other batteries, and hazardous materials are either prohibited or removed from the tipping floor by crane operators and other personnel. In conjunction with recycling programs implemented in some areas, there may be front end separation of other materials.

Modular mass burning facilities employ one or more small scale combustion units to process lesser quantities of waste than waterwall combustors. This type of W-T-E plant is usually pre-fabricated and can be shipped fully assembled or in modules to a construction site. Steam is the energy product most commonly generated from heat recovered from hot flue gases and many modular plants use a two-chamber design to accomplish this task. Flue gases, which contain incompletely burned materials, are then channeled into a secondary chamber where final combustion occurs.

The refuse-derived fuel (RDF) technologies employ a two-stage production-incineration system. Wastes are pre-processed to produce a more homogeneous fuel product (RDF) rather than raw MSW. The RDF is either sold to outside customers or burned on-site in a "dedicated" furnace. The refuse is usually shredded to reduce particle size for burning in semi-suspension or suspension-fired furnaces. Ferrous metals may be recovered using magnetic separators and glass; grit and sand may also be removed by screening. In some RDF plants, air classifiers, trommel screens or rotary drums are employed to further process the fuel products by eliminating additional non-combustible materials.

Several more complex RDF processes have been developed that create powdered, pelletized, "wet pulped" and gasified fuel products. The track record of these technologies has been largely unsuccessful. The most promising of the new RDF technologies involves the burning of wastes in fluidized-bed furnaces which may be more efficient and less polluting than conventional boilers. RDF has been successfully co-fired with coal in a number of installations and attempts are being made to co-dispose RDF and sewage sludge.

The type of technology employed at WTE projects has shifted over the past decade. For purposes of illustration, Table 2 groups facilities into three major types of technology: 1) mass burning, employing either waterwall designs, refractory furnaces or rotary combustors; 2) refuse-derived fuel (RDF) technologies in which wastes are shredded, pelletized or densified for use as a fuel either in a dedicated boiler or as a supplemental fuel; and 3) modular incineration, in which the refuse is burned in a small, prefabricated unit. The few projects employing other technologies such as pyrolysis have not been included in this table.

The reliance on mass burning technologies has grown; as of 1993, this technology is found in 52% of the facilities that are operating or in advanced stages of planning. Modular incineration is now the second most employed process, found in 27% of the projects. The use of modular incineration, however, peaked in 1988 and has been declining since that time. Very few modular units are currently being planned and several have been closed since 1988. Most of these plants did not have air pollution control devices, relying on their after-burn or two-chamber design for emissions control. In addition, retrofitting modular units to meet BACT is often uneconomic.

RDF technologies appeared to have reached a plateau of about 22% of all projects. These processes incorporated front-end materials separation into their designs and were once viewed as a low cost, low maintenance alternative to mass burning. However, many RDF plants have had problematic operating histories.

Table 2. Type of technology by year

	Year				
Technology	1984	1986	1988	1990	1993
Mass Burning[2]	40.7%[1] (46)	46.4% (77)	47.8% (96)	52.0% (105)	51.5% (88)
RDF[3]	23.9% (27)	18.1% (30)	17.9% (36)	21.3% (43)	21.6% (37)
Modular	35.4% (40)	35.5% (59)	34.3% (69)	26.7% (54)	26.9% (46)
Total % (Total #)	**100.0% (113)**	**100.0% (166)**	**100.0% (201)**	**100.0% (202)**	**100.0% (171)**

[1] Percentage of column.
[2] Mass burning includes waterwall and refractory furnaces, as well as co-disposal with sludge and tire burning facilities.
[3] RDF includes all types of RDF processes such as fluff, coarse and pellets.

Source: **1993-94 Resource Recovery Yearbook (New York: GAA, Inc.), 1993.**

Landfill Gas-To-Energy Projects

Another source of biomass energy is solid waste which has already been disposed in landfills. Methane is a natural by-product of the breakdown of organic materials and occurs in all landfills where refuse has been disposed. Both the collection of the methane gas and its processing have been occurring since the late 1970s. Recent regulations concerning control of gas migration and containment of the methane gas to reduce greenhouse gas emissions has stimulated the growth of this energy source.

The degree of methane produced and thus the suitability of landfills as an energy source is a function of the size, age, moisture characteristics, type of waste, depth of fill and climatic conditions of the landfill. The improvement of technology and experience in collecting the gas has resulted in the spread of collection and processing to smaller landfills.

Since 1982 when GAA, Inc. first started tracking the Landfill Gas to Energy projects, there has been a fifteen-fold growth in the number of projects. Figure 4 shows number of projects by category, planned, existing, and shutdown from the years 1982 to 1994. In absolute numbers, each year has shown an increase in total projects. In the three year period, 1991 through 1994, total number of facilities grew by 35%!!

Some changes occurred with respect to the landfills on which methane gas processing was taking place over the twelve year period. Average landfill acres rose through 1991, from 169 acres in 1984, 154 acres in 1986, 205 acres in 1988, to 207 acres in 1991. This acreage dropped by one-half in 1994 to 102 acres. On average, landfill gas processing is occurring at substantially smaller landfills than in the past. This trend may be due in part to improvements in landfill gas collection and processing technology which makes it worthwhile to apply them to smaller landfills.

The amount of gas produced and collected from a landfill varies according to a number of factors, previously discussed in this book. Interestingly, if one examines the average gas flow rate per landfill per day as measured in standard cubic feet, one can conclude that it has been steadily rising from about 1.9 million scfd in 1984 to 2.7 million scfd in 1994. Conversely, as has been mentioned above average, landfill acres upon which projects are cited have dropped. These trends are shown on Figure 5. What the numbers are showing is an increase in experience and improvement in technology which is permitting a better flow of gas to be obtained from smaller sites.

More dramatic is the growth in the total amount of gas being processed at landfills in the United States over the last decade. As shown in figure 6, total gas produced and measured has jumped from about 144 million scfd in 1984 to 541 million scfd in 1994 an increase of about 400 percent.

Landfill gas to energy plants take the collected methane gas and process it to produce a high BTU gas or a low to medium BTU gas. The high BTU gas can be added directly to a natural gas pipeline. The low to medium BTU gas can be used to fuel an engine or turbine to produce electricity or used in a gas-fired boiler. In 1984, about

19% of all projects processed or plan to process a high BTU gas. This percentage dropped steadily through the decade. By 1994, only four percent of projects fall into the high BTU gas category. The decline in the production of pipeline quality gas is related to the high cost of cleaning the landfill gas and the falling prices of natural gas that substantially reduced revenues of these types of projects. It simply became more economic to spend less money on cleaning the landfill gas and use the low or medium BTU product to produce electricity.

The average power output rating achieved by landfill gas to energy plants has risen substantially from 1900 kilowatts in 1984 to about 4400 kilowatts in 1994. In part, this increase has come about by the development of a few large power plants, particularly the 50,000 kilowatt project which came on line on the Puente Hill landfill in Los Angeles County in 1987. Over the ten year period, 1984 to 1994, studied by the author, total megawatt production across all plants has risen substantially. Total electricity produced has increased from 78 megawatts in 1984 to 645 megawatts in 1994. Just for the purposes of comparison a major power plant in the United States produces about 1000 megawatts of electricity.

Conclusion

There has been some growth in the reliance on biomass as an energy source. In absolute numbers, increases have come in wood and solid waste. Landfill gas recovery is on the increase. However, use of municipal refuse as a fuel may have peaked. Similarly, alcohol fuel consumption seems to have remained stable and not a factor in most regions of the country.

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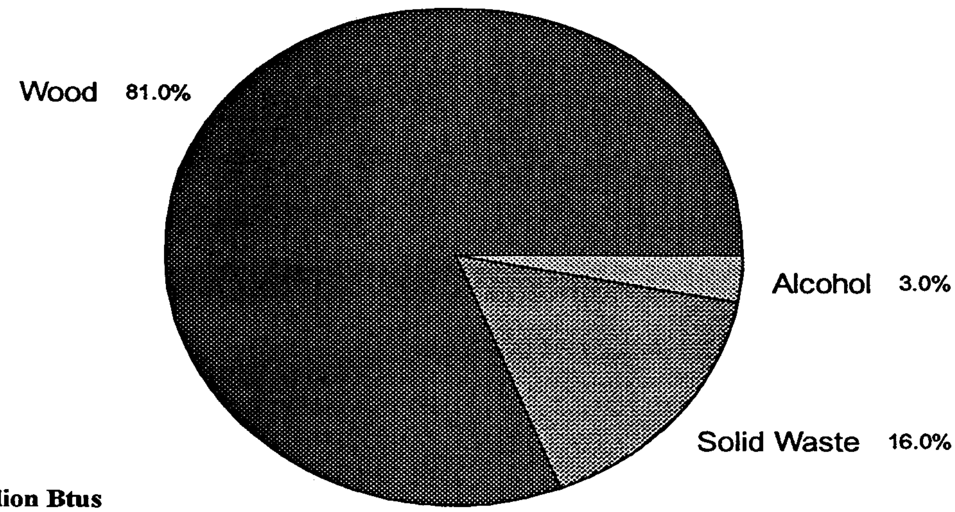
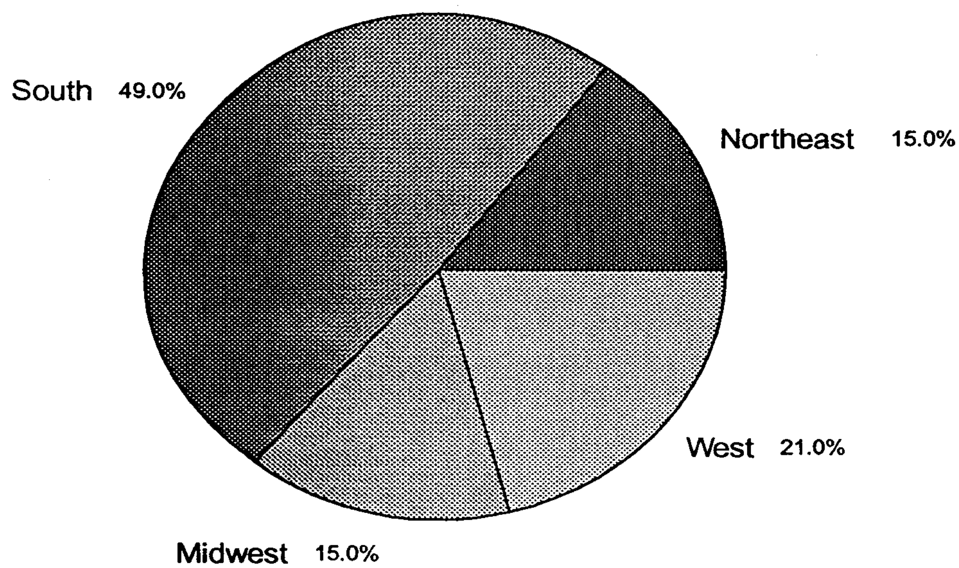
Figure 1: U.S. Biomass Energy Consumption By Type



Total Biomass Energy Consumed = 2785 trillion Btus

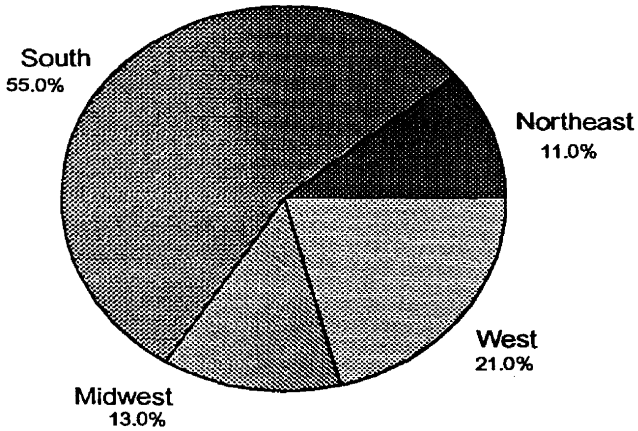
Figure 2: Regional Distribution of Biomass Use



Source: U.S. DOE, Estimates of U.S. Biomass Energy Consumption, 1992, May 1994, p. viii.

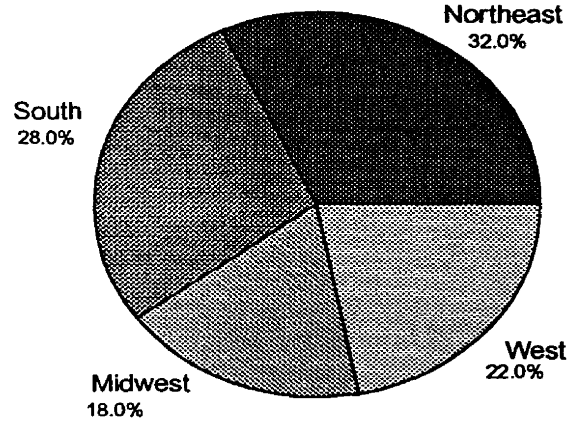
Figure 3: U.S. Biomass Consumption by Type and Region

Wood



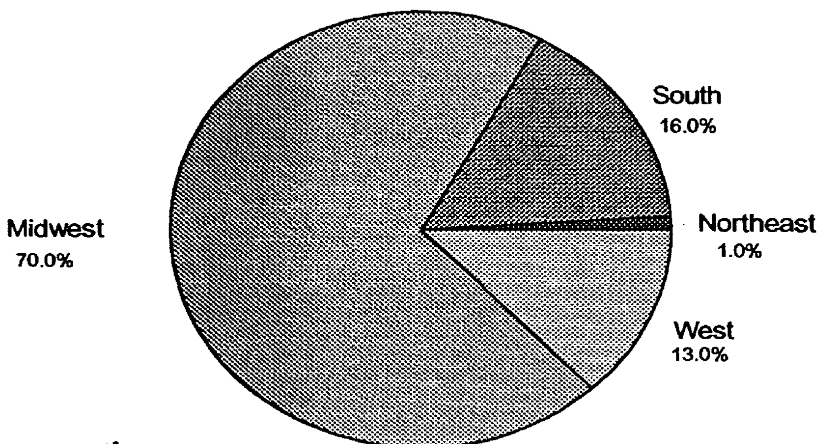
Total Wood Consumption = 2249 trillion Btus

Solid Waste



Total Solid Waste Consumption = 457 trillion Btus

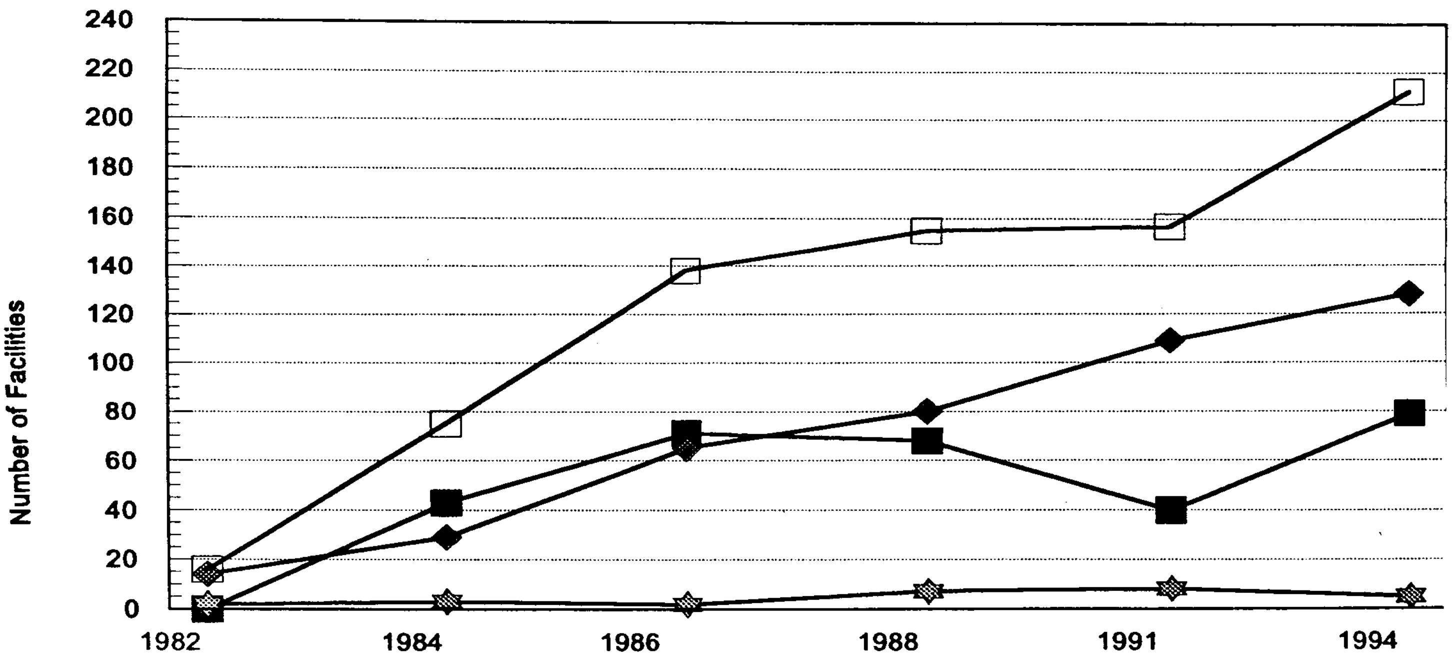
Alcohol



Total Alcohol Consumption = 79 trillion Btus

Source: U.S. DOE, Estimates of U.S. Biomass Consumption, 1992, May 1994, p. viii

Figure 4: Number of Landfill Gas Facilities By Category: 1982-1994.



Source: 1994-95 Methane Recovery From Landfill Yearbook (New York: GAA, Inc., 1994).

KEY
Star = Shutdown
Diamond = Planned
Dark Square = Existing
Light Square = Total

Figure 5: Average Gas Flow (scfd) & Average Landfill Acres: 1984-1994.

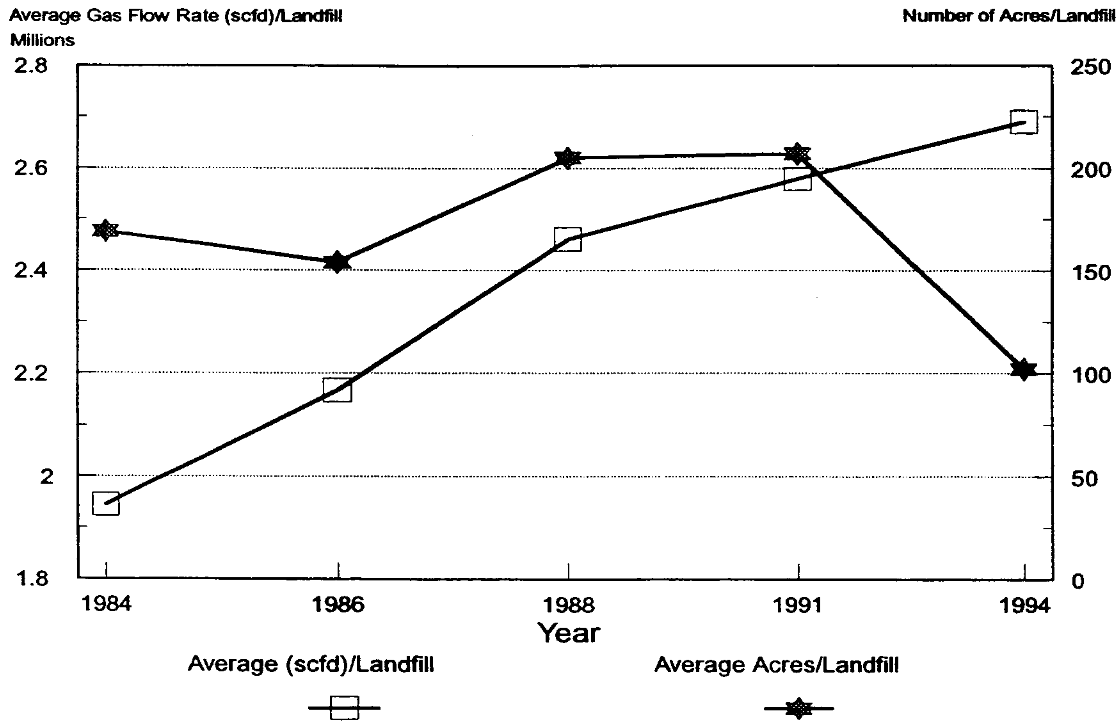
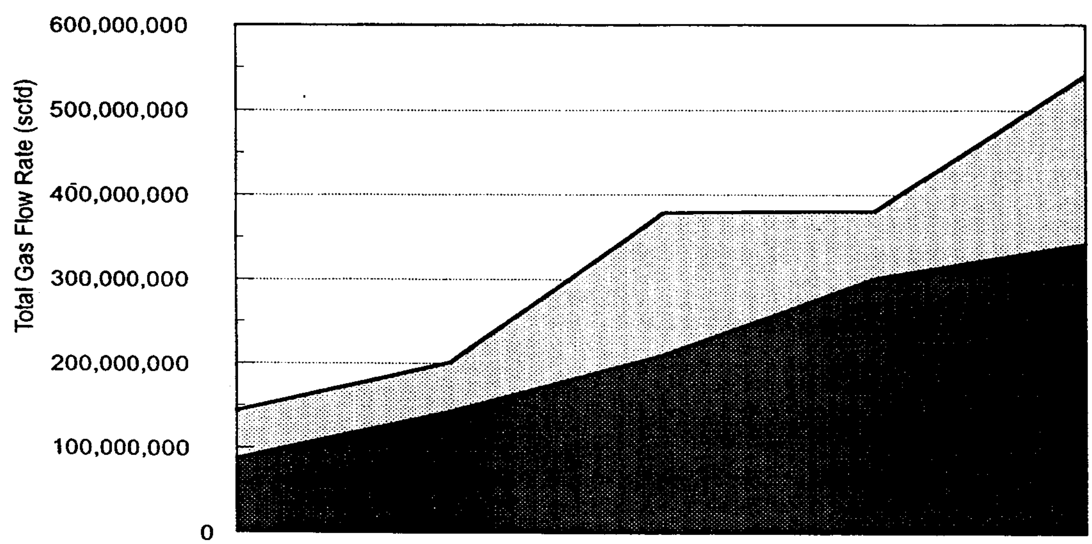


Figure 6: Total Gas Flow Rate LFG Facilities: 1984-1994.



Year	1984	1986	1988	1991	1994
Existing ■	87,088,014	143,728,002	210,773,800	301,970,355	342,744,325
Planned ☐	56,878,010	57,548,998	168,219,200	79,770,000	197,970,904
Total	143,966,024	201,277,000	99 378,993,000	381,740,355	540,715,229

Source: 1994-95 Methane Recovery From Landfill Yearbook (New York: GAA, Inc., 1994).

DEVELOPMENT OF A SYSTEM FOR LONG HAULING CHAFF TO AN ETHANOL FACILITY

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Abstract

The Saskatchewan Research Council in conjunction with Agriculture Canada have conducted a series of projects to evaluate the feasibility of using cereal grain chaff for ethanol production. At present, chaff field collection systems exist; however, chaff's low bulk density currently makes it uneconomical to transport. High transportation costs have a significant effect on the profitability of an ethanol facility. A reduction in transportation costs or technological improvements in processing are required to make chaff an economically feasible feedstock.

Development work at the Prairie Agricultural Machinery Institute (PAMI) is addressing this problem. Laboratory results indicated that long hauling of chaff may be economically feasible when using tractor trailer trucks with compacting equipment. It was determined that particle size reduction had a major impact on transportation economics. Particle orientation by blowing chaff into a bulk storage can increase the bulk density by 66%. The combination of size reduction and particle orientation may provide an effective means for densification. Further work is being conducted to assess the potential of combined size reduction and particle orientation, and to determine the most efficient means of size reduction which could be used as part of pre-transport processing of the chaff.

Introduction

Cereal grain chaff is produced in large volumes on the Canadian prairies and cereal grain growing areas of the United States. For the crop years 1987 to 1991, statistics Canada reported cereal grain production was 28,990,000 tons (26,360,000 tonnes) of wheat and 13,860,000 tons (12,600,000 tonnes) of barley. Detailed data on the actual quantity of chaff produced in Canada is not available since the quantity produced is a function of harvest conditions and the type of soil, combine and crop. Based on extensive field combine test data over a 20 year period at PAMI, it is estimated that conservative chaff to grain ratios are 0.20 for wheat and 0.12 for barley. Using these values, it is estimated that 7,461,000 tons (6,784,000 tonnes) of cereal grain chaff is available annually in Canada. Coxworth and Redekop (1991) suggested that a realistic chaff value for ethanol and feed usage would be $32 to $36 per ton ($35 to $40 per tonne). With an efficient method of collecting the chaff from the field, it was estimated that field prices of about $9/ton ($10/tonne) would be achievable. These prices are expected to be high enough to encourage farmers to collect the chaff in piles. In total, a potential $67,840,000 could be injected into the agricultural economy of the Canadian prairies under full scale implementation.

By definition, chaff is the residual material from cereal grain crops that passes over the combine shoe and is generally dropped on the ground behind the combine. This material consists of glumes, hulls, short straw, weed and crop seeds, leaves and parts of cereal grain heads (Olfert, 1991). Commercial equipment is readily available for collecting chaff. An auger located behind the combine shoe collects chaff directly from the shoe and transfers the material into a blower that blows the chaff into a collection wagon. When the wagon becomes full, the combine operator dumps it and leaves an 800 to 1000 lb (364 to 455 kg) pile of chaff behind in the field. After harvest the chaff piles are picked from the field and transported to a nearby farm for use as a ruminant feed. This provides the local farmer a relatively large, inexpensive alternative to hay.

Chaff can also be used as a suitable feedstock for ethanol production and the chaff byproduct from ethanol production can be used as a ruminant feed for cattle. This synergy of combining livestock and ethanol operations produce significant returns. Lower feedstock costs increases the profitability of the ethanol processing facility. The costs of feeding the cattle can also be reduced as costs are shared between the plant and the livestock facility. The chaff byproduct from the ethanol plant can be fed directly to the livestock or injected in the cattle's drinking water. Above average daily gains have been observed using byproducts from the ethanol facilities based on wheat as a feedstock.

The local farmer also benefits. Collecting cereal grain chaff along with inherent weed and cereal grain seeds benefits crops in the subsequent years. A reduction in weed growth, results in lower herbicide costs and may lower tillage requirements. A reduction in cereal grain seeds lowers the number of volunteer plants in subsequent crop years. Heavy concentrations of chaff in windrows may cause poor seed placement, allelopathic effects or limit the nitrogen availability for the new crop. All of these factors contribute to poor stand establishment and growth in the subsequent crops. Collection of chaff will eliminate these problems and reduce the input costs for local producers, while providing additional revenue to the local farmer.

Due to the chaff's inherently low bulk density of 3 to 5 lb/ft^3 (40 to 80 kg/m^3), the economic viability of collecting chaff is very sensitive to the distance that it must be hauled and transportation costs. Since transportation costs form a high portion of the final value of the chaff, a low cost hauling system, which optimizes payload (by increasing the bulk density), needs to be developed. Energy Mines and Resources Canada and Agriculture and Agri-Food Canada in their ongoing initiative to use agricultural by-products to produce energy have contracted PAMI to develop a system for long hauling cereal grain chaff. Methods of loading, handling and densifying the chaff were assessed and an economic analysis was completed. The results of this analysis are presented within this report as well as recommendations for future work.

Results and Discussion

Chaff Field Removal

The development or implementation of an effective method for removing the chaff from the field piles is the first critical step in developing a successful method of transporting chaff. Several field removal methods were assessed taking into consideration capacity, overall simplicity and the quantity of chaff wasted, rocks picked and dirt collected. Conventional picking equipment was assessed alongside pneumatic picking equipment. The conventional picking equipment left a higher percentage of chaff behind and operated at a low capacity. The pneumatic system, although power intensive, provided greatest capacity and picking ability and appeared to be the best method for removing chaff from the field.

The particular pneumatic collection system evaluated was the Redekop Chaff-O-Matic. This machine is commercially available and has been designed for the purpose of picking chaff piles in order to feed the chaff to cattle. The machine consists of two main components: a header and a blower. The header is comprised of two rotating hollow center augers and a set of picking teeth. The augers transfer the chaff to the air inlet and help suspend the chaff in the air. The picking teeth are mounted on chains running perpendicular to the direction of the machine's travel. They also transfer material to the air inlet and suspend any material left by the augers. When the chaff becomes suspended, it is sucked into the intake of a blower which in turn propels the chaff through a series of ducts to a trailing truck or storage unit.

The Chaff-O-Matic provided superior ground cleaning ability and usually left less than one inch (25 mm) of material depth behind. The superior cleaning ability of this machine was due to the aggressive scraping action of the picking teeth. This aggressive cleaning ability is ideal for the livestock producer who is attempting to maximize the quantity of chaff picked, however, this aggressive action resulted in the inclusion of stones and dirt in the chaff. For industrial applications, the chaff feed stock must be stone-free and dirt-free to avoid damage to the industrial machines. Modifications to the pick up mechanism are required to reduce the aggressiveness of the machine and hence, minimize the collection of stones and dirt.

The capacity of the Chaff-O-Matic was the highest of all machines assessed. The manufacturer's suggested capacity of the commercially available machines is 1500 lb/min (680 kg/min), however, during testing with a pre-production prototype machine, lower capacities in the range of 500 to 800 lb/min (225 to 360 kg/min) were observed and considered acceptable for the application. Tests verifying the rated capacity were never conducted as the tests were focused on the machine's picking ability.

Material Handling of Chaff

Chaff can be moved using belt conveyors, screw-type conveyors or pneumatic conveyors. Straw in the chaff creates the greatest difficulties when handling the product. The straw tends to bridge across openings and cause feeding, conveying and metering problems. Belt conveyors are not significantly affected by chaff, but are limited to low angles of inclination without the aid of slats or buckets. Belt conveyors are the most gentle method of transport and require minimal power. Screw-type conveyors are more rigorous, require minimal power and have little difficulty in moving chaff which contains low straw quantities. Chaff with high concentrations of straw caused bridging at the inlet and within the screw conveyor. Pneumatic conveyors, although consuming the highest amount of power, provide an effective means for conveying chaff. Pneumatic systems have the greatest ability to elevate chaff vertically and provide the added benefit of reorienting and packing the particles which results in a higher density when blown into a storage unit.

Densification

Cereal grain chaff's inherent low density is undoubtedly the most significant factor deterring farmers and industrial purchasers from utilizing chaff as a value-added product. The density of the chaff is dependent on:

- The cereal grain variety
- The composition of the chaff
- The moisture content of the chaff
- Particle size of the chaff components
- Particle orientation

The quantity of straw in the chaff and the physical shape of the cereal grain hull appear to have the most significant effect on the density of the product. The long particle lengths of the straw causes bridging of the chaff and the development of air voids. The curved shape of the cereal grain hull also produce air voids. Eliminating or minimizing this air void volume, through compaction, particle size reduction and particle orientation is expected to significantly increase the density of the chaff.

Compaction

Initial work conducted at PAMI by Lischynski (1992), indicated that cereal grain chaff could be compacted to 10 lb/ft^3 (160 kg/m^3) under a pressure of 16 psi (110 kpa) and to 13.7 lb/ft^3 (220 kg/m^3) under 30.7 psi (210 kpa) of pressure. Repeated pressure recycling resulted in only a 10% increase in density. When the pressure was removed from the control volume, the chaff rebounded to its original state, acting like a perfect spring. This spring-like characteristic of chaff is believed to be due to its cupped shape. From this compaction analysis, PAMI designed two prototype chaff compression trailers (a continuous feed rotary compaction trailer and a reciprocating plunger compaction trailer) and a loading machine for the trailers. Upon completion of the designs, the cost of developing each trailer was assessed and the economics of hauling the chaff was computed. It became quite apparent that the concept of physically compacting the chaff to increase its density required rather large specialized machinery and required highway tractors to unhitch the trailers in the field to allow for filling the trailers which resulted in less efficient method of collection. Due to the size of this equipment, the economic feasibility of the method became questionable. As an alternative, chaff densification through size reduction was explored.

Particle Size Reduction

Reducing chaff particle size has many benefits. Existing wood chip trailer technology could be used to transport the cereal grain chaff from the field to the processing facilities. Technology for unloading these trailers is also readily available. Standard size reduction equipment is readily available in agricultural machinery and industrial machinery.

Due to the farmer's familiarity with standard agricultural equipment, it was decided to assess common agricultural machines for their ability to density the chaff. Chaff was fed through various farm machines. Field testing of a Troy Bilt Shredder illustrated that the density of chaff could be increased by passing material though a screen enclosed fan and allowing the fan to shred the material. Since the method of operation of the Troy Bilt lawn and garden shredder was similar to the concept of the Chaff-O-Matic, modifications were made to the Chaff-O-Matic and tested. Attempts were made to improve the fan's cutting and shredding ability within the fan housing, however, all modifications to the fan significantly hampered the operation of the machine.

Other agricultural machines were then evaluated. Test results from a forage harvester and a hammermill provided the most optimism. A John Deere Model 3800 forage harvester, which uses a cutter-head system to slice forage material was assessed. Chaff was fed into the machine and processed with 1 in (25 mm) wide and 2 3/4 in (45 mm) wide slotted screens. Density increases of up to 81% resulted as shown in Table 1.

A New Holland Model 357 grinder mixer, which comprises of a hammer mill and a mixing tank was fed with chaff while using various round screens with hole sizes ranging from 1/8 to 3/4 in (3 to 19 mm). Chaff density was increased by up to 209% as shown in Table 1.

The results of the hammer mill identified that size reduction was possible, however, the capacity of the agricultural hammer mill was too low. As such, the focus of the project turned to identifying the most effective commercially available mill for reducing chaff particle size.

Following an extensive literature search, 37 North American manufacturers were identified and contacted to discuss which of their equipment may be most suitable for reducing the particle size of chaff. Many types of mills were reviewed including hammermills, disc mills, conical mills, pin mills, roller mills, SEGO mills, ball mills and a Universal FERKAR mill. Samples of chaff were sent to the mill manufacturers who ran the product through their equipment. The manufacturers were required to provide information on the density acquired, the power required and the cost of such equipment. Samples of the processed product were returned to PAMI for further analysis.

Table 1. Hammermill and Forage Harvester Test Results.

Machine	Screen Size in	(mm)	Density lb/ft^3	(kg/m^3)	Density Increase (%)
Hammermill	1/8	(3)	11.48	(184)	209
	1/4	(6)	8.75	(140)	135
	3/4	(19)	5.95	(95)	30
	Raw Chaff		3.72	(60)	0
Forage Harvester	1	(25)	5.87	(81)	81
	2 3/4	(45)	5.20	(83)	60
	Raw Chaff		3.25	(52)	0

Often the manufacturers sold several types of mills. This provided the opportunity to compare several different types of mills side-by-side as well as to obtain recommendations as to which mill was the most suitable for the job. Preliminary results from the manufacturers suggest that disc mills, hammer mills and roller mills should be investigated in greater detail. Further research is being conducted to identify which mill is the most appropriate.

Particle Orientation

Particle orientation can be achieved by either blowing or vibrating the storage volume. When field testing two pneumatic based systems, a Troy Built Shredder and the Chaff-O-Matic, it was found that the blown material had a higher density than dropped material. Blowing the product into the storage container caused the material to distribute and pack better providing a substantial increase in density. Typical chaff in the field at a density of 3 lb/ft^3 (48 kg/m^3) could be increased to approximately 5 lb/ft^3 (80 kg/m^3) by blowing it into the truck with the Chaff-O-Matic. During field testing, the Troy Built Shredder (a miniature lawn and garden shredder) increased chaff density by 46% whereas the Chaff-O-Matic increased the density by 66%.

Tapping or vibrating a storage container had a similar affect to blowing and caused the chaff to settle within the container. Tapping the container was observed to increase the density from 18 to 54%. The resulting increase in chaff density gained by vibrating a large scale storage container are unknown at this time.

Particle orientation appears to have a significant effect on chaff density. Reducing the chaff particle size through a milling process and then orientating the chaff by blowing it into a storage unit is expected to provide significant increases in chaff density. When a system is designed, the combined effects of particle size reduction and particle orientation should be assessed together as the resulting final density may be interrelated to the other operation.

Economics of Long Hauling Chaff

An economic analysis was conducted using the capital cost equation from Audseley and Boyce (1974) with a number of basic assumptions fro equipment capital and operating costs for various chaff densities. The annual capital cost for many of the system components was calculated using the following equation (Audseley and Boyce, 1974).

$$C_C = C * i * [(1 + r)/2 + (1 - r)/2n] + (1 - r)/n$$

Where i is the interest rate, r is the ratio of resale value, n is the life of the equipment, C is the original capital cost of the equipment and C_C is the annual capital cost.

Costs for all systems were based on the assumption of the use of one compactor. All systems were considered as driven by a farm tractor during loading and a highway tractor system during unloading. Annual repair costs were taken as a percentage of the original capital costs. Loading time was assumed to be one hour, with hooking and unhooking the trailers taking 15 minutes, and unloading taking 30 minutes. All hauling was expected to be completed in 8 weeks per year. At 6 days per week and 12 hours per day, the loader would work about 575 hours per year. Travel time was based on the total hauling distance and an average speed of 50 mph (80 km/h).

The costs for each individual component were calculated based on cost per load, and were calculated for several hauling distances. A value of $9/ton ($10/t) was used for cereal grain chaff purchased as small piles in the field, and a price of $38.60/ton ($35/t) was used for chaff delivered to the processing plant. Where possible, accepted rental rates (from the Farm Machinery Custom and Rental Rate Guide, 1995) for system components were used instead of values computed from Audseley and Boyce's equation. This applied to components such as labour, and farm tractor costs. The highway tractor cost was determined by contacting a local trucking firm.

Capital costs of the various components of the various Long Haul Chaff systems along with others cost assumptions are given in Table 2.

The economic analysis results are given in Figure 1. The costs of the size reduction system will not be fully known until the research is completed on selecting an appropriate milling process. The Redekop Chaff-O-Matic has been included as a benchmark for comparison purposes.

Table 2. Costs and Cost Assumptions for Various Long Haul Chaff Systems

Rotary Compactor System		*Reciprocating Compactor System*	
Est. Trailer Cost	$74,000	Est. Trailer Cost	$68,000
Est. Loader Cost	$17,000	Est. Compactor Cost	$25,000
Tractor Size	120 hp(89 kW)	Tractor Size	120 hp(89 kW)
Tractor Cost	$43.56/h	Tractor Cost	$43.56/h
Available Payload	12.9 ton (11.7 t)	Available Payload	12.1 ton (11.9 t)
Size Reduction System		*Redekop Chaff-O-Matic*	
Trailer Cost	$45,000	Trailer Cost	$45,000
Est. Machine Cost	$55,000	Chaff-O-Matic Cost	$15,000
Est. Tractor Size	180 hp(134 kw)	Tractor Size	120 hp
Tractor Cost	$59.42/h	Tractor Cost	$43.56/h
Available Payload*	14.0 ton (12.7 t)	Available Payload**	10.0 ton (9.1 t)
Interest Rate	10%		
Resale Value	15%		
Equipment Lifetime	10 yrs		
Repair Cost	2% of original cost		

* Using a 4,000 ft^3(113 m^3) trailer filled with chaff at a density of 7 lb/ft^3(112 kg/m^3)
**Using a 4,000 ft^3(113 m^3) trailer filled with chaff at a density of 5 lb/ft^3(80 kg/m^3)

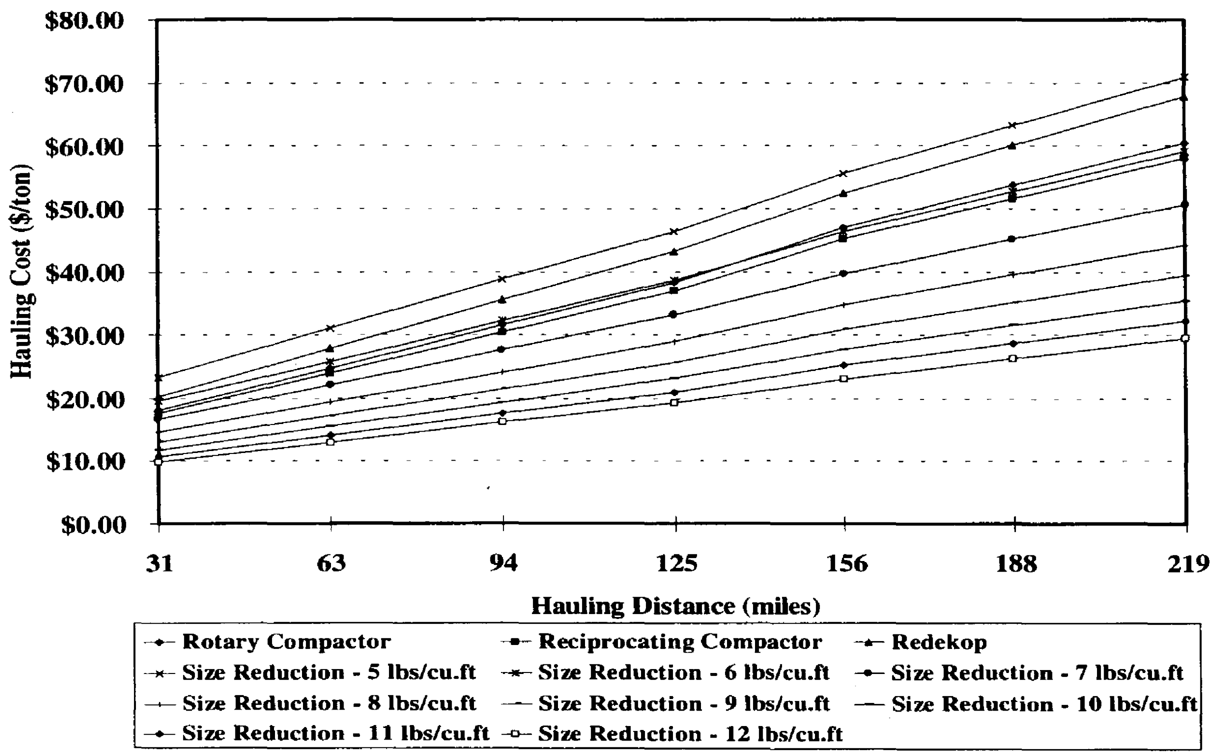

Figure 1. Economic Analysis Results

Recommendations for Future

The economic analysis presented prior to this section illustrates that both compaction and size reduction appear to be feasible methods for transporting chaff over large distances. However, size reduction has several advantages over compaction. The size reduction system is less complex than the compaction method and therefore is expected to have lower capital, operating and maintenance costs. Existing technology can be used and only one specialized machine, developed by adapting existing farm machinery, would be needed. Since the trailers do not have to be modified, they could be used in other industries as well. Convenience would be increased during chaff hauling, as the highway tractors would not have to be unhitched from the trailer during the entire loading, hauling and unloading cycle. Another advantage to size reduction would be that it is the first processing step in the chaff to ethanol process, and doing this step in the field would save the processing plant one operation. Buyers may be more likely to implement this technology more readily due to its lower capital costs.

A further investigation to pinpoint which mill is the most suitable to reduce chaff particle size must be completed. Information on the cost of the mill and the power requirements of the mill will have a significant effect on the overall economics. Should the mill investigation provide positive results and field trials support the results, construction of a prototype chaff size reduction machine could follow. A conceptual illustration showing a potential prototype machine is presented in Figure 2. The prototype machine would use pneumatic suction to lift the chaff from the ground into a size reduction mill. From the mill, the material would be blown to an awaiting truck. A sorting mechanism may also be incorporated to reduce the amount of undesirable material from entering the mill.

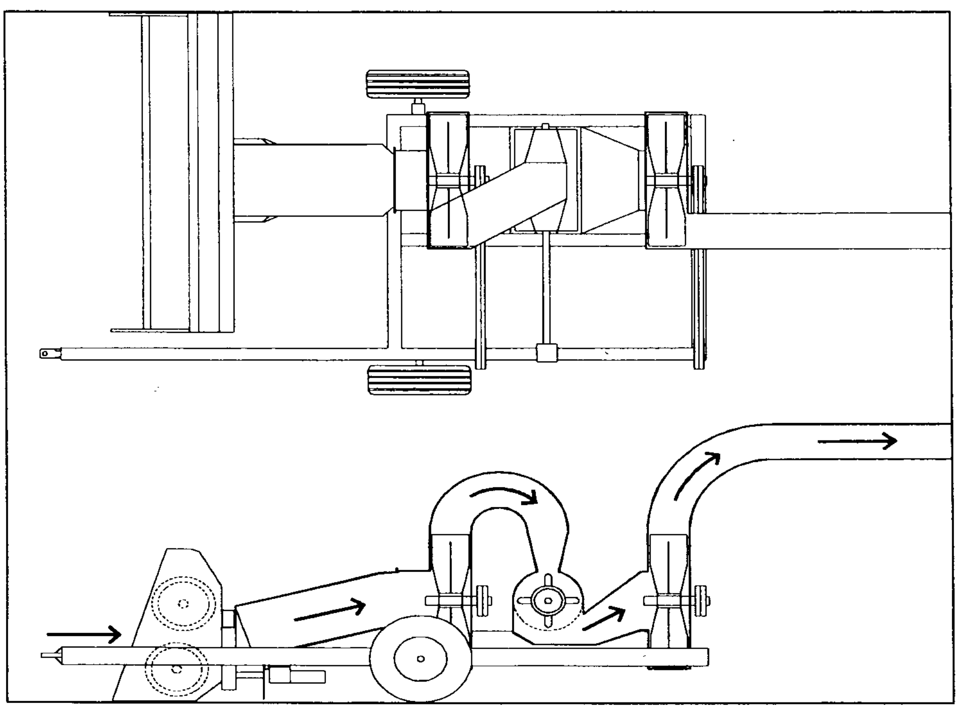

Figure 2. Conceptual Size Reduction Machine

Conclusions

The following conclusions were established from this project:

1. The Redekop Chaff-O-Matic pneumatic collection system appeared to be the best method for picking chaff from the field in comparison to other machines tested. Although it consumes more power than the other systems tested, it provided the greatest capacity and picking ability. Slight modifications to the machine would likely minimize the intake of dirt and stones.
2. Chaff, with low accumulations of straw, can be moved effectively using belt, screw-type and pneumatic conveyors. Pneumatic conveyors, although more power intensive, have the greatest ability to elevate chaff vertically and provide the added benefit of reorienting and packing the chaff particles when discharging into a storage unit.
3. Both compaction and particle size reduction can be used to increase chaff density, however, the particle size reduction system has many inherent benefits.
4. Particle orientation created by blowing the chaff or vibrating the storage unit, can significantly increase chaff density (by as much as 66%).
5. The combined effects of particle size reduction and particle orientation should be assessed together as the resulting final density may be interrelated to the other operation.
6. A further investigation to identify the most suitable mill for chaff size reduction is required and precise information on this mill's capacity, power requirements and cost is needed to complete an accurate economic analysis and guide the design of a prototype field-scale machine.

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PROCESSING AND UTILIZING URBAN WOOD WASTE AND PALLETS FOR FUEL

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Abstract

Industry is currently investigating the potential for recovering, processing and utilizing a number of urban waste materials and selected manufacturing waste for fuel. The emphasis is on relatively clean, low ash, high BTU Urban Fuels that might be obtained at substantially reduced cost over conventional fuels.

Results from recently completed studies by the Council of Great Lakes Governors Regional Biomass Energy Program, show urban wood waste to be an important source of energy comparing favorably to other urban waste fuels.

The GLRBEP Studies (1), which are reviewed in this paper, examined the types, quantities, current disposition, energy potential and potential markets for urban wood waste in large Metropolitan areas of a five state region including Illinois, Iowa, Minnesota, Ohio and Wisconsin.

The studies build on an earlier, 1993 US Forest Products Industry Study (2) which determined facility capital and operating costs for urban wood processing and combustion systems and environmental and regulatory considerations over a range of facility sizes.

Net costs to make urban wood fuel available and avoided disposal costs are reviewed. Incentives, methods of sorting and opportunities to salvage urban wood waste and other combustible waste are discussed. Drawing on various studies and Industry experience urban wood fuels are compared to other urban waste fuels.

INTRODUCTION

The history of technologies in the United States that recover energy from urban solid waste is relatively short. Most of the technology as we know it evolved over the past 25 years. This evolution led to the development of about 100 modern mass burn and RDF type waste-to-energy plants and numerous small modular combustion systems, which collectively are handling about 20%, or about 40 million tons per year, of the nations municipal solid waste.

Technologies also evolved during this period to co-fire urban waste materials with other fuels or selectively burn specific waste streams as primary fuels. Building on past experience and working through problem areas that often plagued early projects a growing number of second or third generation urban waste fuels projects are being developed.

This presentation presents findings from our 1994 GLRBEP (1) and 1993 FPL Urban Wood Waste Studies (2) of the potential to recover and utilize urban wood fuels. It compares urban wood waste fuel to other urban waste fuels and describes opportunities for the power industry to recover and utilize clean, high heat value, low ash alternative fuels from municipal and industrial solid waste.

Many in industry feel that the power industry and the private solid waste management sector including waste fuel and scrap processors should be able to develop mutually beneficial or win - win urban solid waste fuel supply fuel use projects.

Such projects could provide attractive cost savings to both industries and induce those who produce or dispose of large quantities of solid waste to act as merchant processors and produce good quality fuels which the power industry can use. Their motivation is control of hauling and disposal costs, conserving landfill space and extending landfill life. Independent fuel processors may work in competition with these organizations or provide a service to both.

Alternative Urban Waste Fuels/Per Capita Potential

The potential for using manufactured urban waste fuels improves when the availability of other waste fuels and the potential for fuel blending or enhancement is considered.

Fuel blending of coals is becoming common practice in the power industry with important environmental and cost advantages. Similar potential exists with urban fuels to develop fuel mixtures i.e. wood and rubber, wood and plastic, etc., that will not derate existing combustion units or will justify more efficient new units while providing low cost, low sulfur fuels.

Table 1 (3) summarizes the per capita potential for six categories of urban solid waste fuels including data on wood waste from our recently completed five state study for the Council of Great Lakes Governors Regional Biomass Energy Program. (1) The table indicates a potential of 11.7 trillion BTU/Year of available energy per million population for the six listed urban fuels. This is the equivalent of 820,000 tons per year of 7,000 BTU/LB fuel.

As shown by Table 1 the energy available in urban wood waste is one of the leading sources of energy available from urban waste fuels.

TABLE 1
URBAN SOLID WASTE FUELS - PER CAPITA POTENTIAL (3)

Urban Fuel	Lb/Cap/Day	Energy Potential Trillion BTU/YR Per Million Population	Percent of Total Power Generation Use 1) Electric Utility	Industrial
Urban Wood Waste 2)				
MSW Wood	0.32	0.8	0.8	1.6
C & D Wood	0.44	1.1	1.1	2.2
Tree Residue 3)	0.48	0.8	0.8	1.6
Included In Above				
Wood Pallets	(0.14)	0.4	0.4	0.8
R.R. Ties	(0.04)	0.1	0.1	0.2
Tire Derived Fuel 4)				
1Yr. Stockpile	0.4	2.3	2.3	4.6
Annual	0.05	0.3	0.3	0.6
Non Recycled Paper 5)	Up To 0.66	1.7	1.7	3.4
Non Recycled Plastic 6)	---	---	---	---
Classified Auto Shredder Residue 7)				
Heavies (Rubber)	0.03	0.2	0.2	0.4
Lights (Fiber & Plastic)	0.11	0.4	0.4	0.8
Refuse Derived Fuel 8) (from MSW) (After current energy use & 35% recycling)	1.8	3.8	3.8	7.6
Domestic Sludge 9)	0.12 Dried	0.3	0.3	0.6
	---	11.7	11.7	23.4

Table 1 notes

1) Annual energy use per million population in the Midwest is about 300 trillion BTU/YR. Electric utility use is about 1/3 and industrial use is about 1/6.
2) Based on data average of 5 state study by M.L. Smith environmental. (1)
3) Excludes approximately 20% for tops & brush & other wood unusable for fuel.
4) Data average from studies by Monsanto, Commonwealth Edison, Illinois Power, Wisconsin Power & Light, Scrap Tire Council, and Illinois Department of Energy. (4) (5) (6) (7)
5) Based on data average from NCASI studies. (8)
6) Types and quantities of non recycled plastic, generated through plastics industry programs, available as fuel are under study by M.L. Smith Environmental and Associates.
7) Consultant studies. Fractions contain less than 5% inerts.
8) 190 million tons X .8 available X .65 after recycling X .84 process recovery ÷250 million X 2000 lbs ÷365.
9) Consultant studies based on survey of 10 major cities and collection and analysis of Houston, TX 69th Street Plant dried sludge by M.L. Smith Environmental (9) and National Sewage Sludge Survey (10).

The combustion properties of selected urban waste fuels are shown in Table 2. While rubber and plastics fuels have higher heat values, the fuel properties of wood compare favorably to most urban waste fuels.

TABLE 2
COMBUSTION PROPERTIES - URBAN SOLID WASTE FUELS (3)

	Mixed Urban Wood Waste (Non-Forestry)	Urban Tree Residue	Tire Derived Fuel	Non Recycled Plastic (Ground Polystyrene)	Refuse Derived Fuels	Densified Non Recycled Paper Fuel	Classified Auto Shredder Residue (With loose dirt & glass removed)	
							Heavy	Light
HHV (BTU/LB)	7,136	4,500	15,461	17,263	5,750	8,430	14,082	9,699
Proximate % As Received								
Volatile	66.1	41.1	66.0	96.97	58.5	76.9	62.1	67.7
Fixed Carbon	11.9	10.6	24.6	0.34	6.9	5.5	24.0	4.6
Ash	2.5	1.2	8.9	2.3	12.48	6.8	12.6	22.6
Moisture	16.0	47.0	0.5	0.39	21.89	10.8	1.3	5.1
Sulfur	0.1	0.1	1.4	0.06	0.20	0.1	1.0	0.4

Major Sources/Opportunities to Obtain Urban Waste Fuels

Changes in urban solid waste collection practice (with separate handling of yard waste and recyclables), increased industry participation in recycling programs, and continued growth of the solid waste processing industry have improved this opportunity to manufacture fuels from urban waste. (11) (12)

Major sources/opportunities to obtain urban wood waste and other urban waste fuels are through organizations such as those listed in Table 3 which are becoming increasingly active in supply of these fuels. (5) (9)

TABLE 3
Sources/Opportunities To Obtain Urban Waste Fuels

1. Large Urban Landfills/Transfer Stations
- **Taking Inventory of Waste Received**
- **Shredding Wood Waste For Fuel**
- **Shredding Tires For Fuel**

2. Urban Wood Processors

3. Urban Tire Processors

4. Urban Refuse Derived Fuel Facilities

5. Urban Recyclers - Paper & Plastic
(Paper industry and plastics industry suppliers and users)

6. Large Urban Scrap Shredders

150 - 200 Centrally Located In Major U.S. Cities
Some Are Using Excess Capacity to Process Urban Wood Waste and Other Urban Waste Materials for Fuels and Other Uses
Have Extensive Contacts With Local Manufacturing Industry
Can Be Central Waste Processor/Transfer Station

The information presented here from ML Smith Environmental & Associates Urban Wood Waste Studies and given for other urban waste fuel is based on consultant cost studies using vendor quotations and consultant inhouse data bases, consultant surveys*, surveys and data bases from State EPAs, District Engineers, Department of Natural Resources, Energy Bureaus, Forestry Services, Utility Commissions and Ongoing work with the energy industry and private solid waste sectors.

* Cities, Counties, Recycling Coordinators, Landfills, Waste-to-Energy Plants, Industry, Utilities.

The Estimated per capita wood waste generation in the 5 Midwest states studied is shown in Table 4.

TABLE 4
PER CAPITA URBAN WOOD WASTE GENERATION
LB/CAP/DAY (1)

	Illinois	Iowa	Minnesota	Ohio	Wisconsin	5 State Average *
Residential, Instutional, & Commercial	0.1529			0.2269		
Manufacturing	0.1983	} 0.185	} 0.443	0.2778	} 0.1215	} 0.321
Tree Residue (Brush & Logs)	0.1186	0.200	0.778	1.1690	0.1109	0.475
Construction & Demolition Wood	0.3086	0.303	0.314	0.8475	0.4448	0.444
Total	0.7784	0.688	1.535	2.5212	0.6772	1.24

* Unweighted

Disposition of Urban Wood Waste

Discarded wood pallet waste averaging about 0.14 Lb/Cap/Day is handled many ways. Possibly one third or more is disposed of by landfill, etc. another quarter is given to park districts and the general public for various uses and firewood, etc. Most of the balance is processed into products onsite or offsite (via clean wood brokers and processors) to produce animal bedding, landscaping and architectural mulch, (may be dyed various colors), fuels, wood fillers for wood products industry, oil absorbants, etc.

Used railroad ties averaging about 0.04 Lb/Cap/Day are typically stockpiled along railroad right of ways prior to disposal. Various construction and architectural uses. Some sold to or used by nurseries, some given to or handled by wood brokers and processors. Some processed and used as fuel. Railroads are looking for solutions and will railhaul to user sites.

Costs for disposal per tire vary form cars to trucks but average about the same per ton. Used as intermediate landfill cover in some areas.

Urban Tree Residue averaging about 0.48 Lb/Cap/Day is mostly stored or given away and is frequently processed or chipped first. The balance is used as bulk agent in yard waste Composting, sold as landscaping or architectural mulch, (may be dyed various colors), or animal bedding, burned at brush burning sites or burned for energy. A small portion is sawed. Stumps and large unwanted logs are often included with demolition debris.

Construction and Demolition Wood, C & D wood waste averaging about 0.44 Lb/Cap/Day is mostly landfilled at this time. This wood has good potential for sorting and processing into wood fuel. It often also includes wood from each of the above categories and some of the broken pallets, skids, wood shipping crates, and spare parts from manufacturing operations. Some specialized demo fill only sites and large multipurpose sanitary landfills which handle mixed C & D wood are beginning to sort and process clean demolition wood, wood pallets, etc. into fuel and other products. This is also done in conjunction with recovery of aggregate used asphalt and metals. Wood in C & D waste is often over 50% by volume and more than 30% by weight.

Mixed Municipal Solid Waste Wood The wood in this category averaging about 0.32 Lb/Cap/Day includes co-mingled municipal solid waste (residential and institutional solid waste). Manufacturing solid waste is collected separately and is often disposed of with other MSW in multipurpose sanitary landfills, waste to energy plants, etc., or in C & D sites or private landfills. The wood waste is typically disposed with other waste.

Urban Wood Waste Processing Cost

The urban wood waste cost studies evaluated four primary breaking methods for wood fuel sizing and six facility sizes. Where two stage size reduction is employed i.e. facility sizes 4, 5, & 6 in the following Table, Hammermills are assumed for final sizing.

The specification of the wood fuel produced is minus 2" splintered wood fuel free of metal with approximately 2½% ash, 16% moisture and 7,100 BTU/LB heat value.

Table 5 provides operating cost per ton and power usage in KW Hours (KW-HR) per ton for the various sized urban wood processing systems.

TABLE 5
URBAN WOOD PROCESSING COSTS (2)

Facility Size	Tons Per Year	Total Capital Cost	Total Cost Per Ton	KW - HR Per Ton
1 C	880	$1,000.00	133	58
2 C	2,750	$355.20	52	30
3 C	5,540	$464.40	47	30
4 A	15,600	$1,981.10	50	29
4 B	15,600	$1,922.90	49	25
4 C	15,600	$1,961.90	52	29
4 D	15,600	$1,991.50	48	24
5 A	32,300	$2,807.10	36	23
5 B	32,300	$2,476.40	33	20
5 C	32,300	$2,480.40	34	22
5 D	32,300	$2,549.60	32	18
6 A	109,000	$5,046.70	19	20
6 B	109,000	$4,563.10	17	17
6 C	109,000	$4,665.80	20	20
6 D	109,000	$5,394.70	19	15

1) A - High torque crusher/rotary shear, B - Hammermill, C - Tub Grinder, D - Auger Shredder

Urban Wood Combustion Costs

The urban wood waste cost studies evaluated the capital and operating cost and income of wood energy systems for twelve conditions as noted below.

TABLE 6
URBAN WOOD COMBUSTION COSTS (2)

Plant Size 1)	Plant Type	Cost Income Per Ton $	Wood Fired Boiler Efficiency	Percent Utilization
1	2.25 MM BTU/Hr Hot Air System	42.28	65	80

2	7.00 MM BTU/Hr Hot Air System	28.82	68	80
3	10,000 Lb/Hr Saturated Steam	37.01	71	80
4	25,000 Lb/Hr Saturated Steam	29.12	71	84
5A	50,000 Lb/Hr Saturated Steam	45.83	76	86
5B	50,000 Lb/Hr Saturated Steam	57.99	76	84
5C	50,000 Lb/Hr Saturated Steam	63.08	77	85
5D	50,000 Lb/Hr Saturated Steam	(9.63)	76	83
6A	150,000 Lb/Hr Superheated Steam	12.55	77	93
6B	150,000 Lb/Hr Superheated Steam	14.10	77	85
6C	150,000 Lb/Hr Superheated Steam	18.40	79	87
6D	150,000 Lb/Hr Superheated Steam	(17.46)	77	87

1) Annual Quantities same as TABLE 5.
A - Stream to local buyer, B - Electrical Generation Stoker, C - Electrical Generation Fluid Bed, D - Existing coal plant retrofit Revenue assumptions. Wood available at no cost. Hot Air and Steam Supply Systems displace Natural Gas at $3.00 per million BTU, Electrical Systems sell power at $0.05 per KW-HR to local utility grid, Displaced Coal Systems displace coal at $2.50 per million BTU (1993 conditions)

TABLE 7
Avoided Disposal Costs Of Potential Urban Solid Waste Fuels (Midwest Conditions) (1) (9) (10)

Source Of Alternative Fuel	Median Disposal Cost Per Ton
Municipal Solid Waste	$25 - $35
Domestic Sludge	
If received dewatered to 70% moisture	$150 - $185
If received at 1.5% solids	$300 - $350
Urban Wood Waste	
MSW	$25 - $35
Construction & Demolition	$20 - $25
Tree Residue	
Brush	$15 - $20
Logs	$10 - $15
Stumps	$35 - $40
Rubber Tires	
Cars or Trucks	$50 - $100
Auto Shredder Residue 1)	$15 - $30

1) Used as intermediate landfill cover in some ares.

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ASH FROM THE COMBUSTION OF TREATED WOOD: CHARACTERISTICS AND MANAGEMENT OPTIONS

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Abstract

Continued research and development of environmentally-acceptable and cost-effective end uses for wood ash is having a significant affect on the ability to use wood and wood waste for fuel. This is particularly true for ash resulting from treated wood combustion. Concerns about the contents of ash from wood containing paint, stain, preservatives, or other chemicals is one of the largest regulatory barriers to its use as fuel. This paper:

- Explains the types of "clean, untreated" and "treated" wood that are likely to produce ash that can be beneficially used.

- Presents preliminary results from a study sponsored by the New York State Energy Research and Development Authority (NYSERDA) on ash characteristics and end uses. The study sampled and analyzed ash generated during test burns of five treated wood wastes at an 18 MW wood-fired power plant.

- Describes existing and potential end uses for untreated and treated wood ash.

1. THE REGULATORY FRAMEWORK FOR WOOD ASH

The combined experience of wood waste processing facilities, operators of existing wood-fired facilities, and developers of new wood-fired power plants indicate that if a new wood-fired facility is being considered, there is substantial interest in using wood waste as fuel. However, concerns about environmental regulations and ash disposal costs are cited as key barriers preventing the use of wood waste as fuel, especially if the fuel may contain treated wood. A variety of federal and state regulations address the definition or classification of ash produced from the combustion of untreated or treated wood.

Federal regulations that apply to wood ash are contained in the Resource Conservation and Recovery Act of 1976 (RCRA) and the Hazardous and Solid Waste Amendments of 1984. RCRA and the 1984 amendments define what materials are classified as "solid" and "hazardous" waste, and establish the regulatory framework under which waste must be managed or discarded. RCRA defines solid waste "as any discarded material." RCRA does not specifically define wood ash as a solid waste. However, under RCRA all types of discarded material are classified as solid waste, unless the material exhibits any one of four hazardous characteristics (in which case, the material is then classified as hazardous waste).

The characteristics that affect whether wood ash is hazardous are corrosivity and toxicity. Although corrosivity generally applies to liquids, in some cases it may also apply to ashes. Many ashes generated during the combustion of wood in utility-scale facilities are wetted (or "quenched") with water to extinguish live embers and to control dust emissions. In addition, ash may be stockpiled outdoors and exposed to precipitation. Free water may leach from ash stockpiles, and the resulting leachate may have a pH in excess of 12.5. Due to the potential for leachate to be produced by ash stockpiles, at least one state (Washington) has established regulations for wood ash that include testing for pH.

Although RCRA applies to all solid (and hazardous) waste generated in the U.S., most states have promulgated solid waste programs and regulations to manage solid waste in their state. State solid waste regulations must be equivalent to, or more stringent than RCRA. Aspects of state regulations that apply to wood ash include:

- Definitions of wood ash. Some state solid waste regulations contain specific definitions for untreated or treated wood ash.

- Provisions for the beneficial use of solid wastes. Some state regulations provide for the beneficial use of a solid waste. An example is the use of wood ash as a liming agent, replacing other materials such as ground limestone. Solid waste that is beneficially used may be exempt from solid waste regulations. However, in order to be beneficially used, the material must not be hazardous, and its use must have minimal or no potential to contaminate groundwater, surface waters, or soil.

2. WOOD ASH CHARACTERISTICS AFFECTING BENEFICIAL USES

The TCLP analysis is often the first test state regulators require when determining the appropriate management of a waste material, such as wood ash. According to RCRA, waste is considered to be hazardous if the TCLP analysis results in one or more metals exceeding limits established by EPA.

In addition to RCRA, EPA has promulgated regulations pertaining to the use and disposal of sewage sludge and septage (40 CFR Part 503). Commonly referred to as the "Part 503 regulations," the regulations establish the minimum standards sludges from wastewater treatment facilities must meet in order to be land applied. The Part 503 regulations must be adopted as minimum requirements by states. However, states can promulgate more stringent regulations, if it is deemed necessary. The Part 503 regulations contain two sets of numerical limits for elemental metals that pertain to sludges that are to be land applied. The "ceiling concentrations" establish the upper limit for metals concentrations. The "pollution concentrations" establish more stringent metal concentrations, and sludges that meet these limits receive less regulatory oversight. In many states, the numerical limits in the federal Part 503 regulations will be adopted and used to regulate the land application of other solid waste materials, such as wood ash, in addition to sewage sludge and septage. Since one of the largest existing and potential end uses for wood ash is land application as a liming agent and/or source of nutrients, the Part 503 regulations are expected to have a direct impact on future wood ash land application activities.

Presented below is a summary of the types of wood ash expected to pass the TCLP and to meet Part 503 regulations for land application. The information is based on data from a variety of laboratory and full-scale test burns.

- Ash from wood treated with **organic-based preservatives**, such as creosote and pentachlorophenol, can be expected to meet both TCLP metal standards and Part 503 concentration levels for land application. CTD is aware of at least one facility that is land applying creosote-treated wood ash in a state-approved program. TCLP data on pentachlorophenol-treated wood ash can be relatively high for chromium, although they have been found to be below regulatory levels. Chromium levels in the TCLP extract may be of concern for land application or other uses for the ash.

- Ash from wood containing **organic-based adhesives**, such as urea formaldehyde and phenol formaldehyde, can be expected to meet both TCLP metal standards and Part 503 concentration levels for land application. This is because the adhesives typically do not contain significant quantities of metals, and the resulting ash should also have low levels of elemental and TCLP metals.

- Data from **CCA-treated wood** combusted either in a laboratory or at a wood-fired power plant indicates the ash is expected to exceed the TCLP limit for arsenic and chromium, and Part 503 regulations for arsenic, chromium, and copper. Ash that exceeds TCLP limits are classified as a hazardous waste under RCRA, and are likely to have minimal, if any, end uses.

- Ash from the laboratory combustion of woodfuel samples processed by several wood waste processors who accept a variety of **"urban" wood waste** materials have variable TCLP and elemental metals results. However, processors can limit the amount of treated wood they accept, and/or separate and remove treated wood during processing. It is expected that woodfuel processed by facilities who actively monitor and limit the types and amounts of treated wood waste they accept, and separate out treated wood waste during processing could meet TCLP and Part 503 limits. However, this will depend on the extent of feedstock inspection, sorting, processing, and quality control used at an individual facility.

3. NYSERDA STUDY OF TREATED WOOD ASH CHARACTERISTICS

C.T. Donovan Associates, Inc. and BFI Organics, Inc. are currently completing a study on treated wood ash characteristics and end uses for the New York State Energy Research and Development Authority. As part of the study, test burns of five types of treated wood and one clean, untreated wood were conducted at an 18 MW wood-fired power plant. Ash generated by the test burns are being tested for physical, chemical, and environmental characteristics. In addition, each ash is being used to create an ash-concrete product, which is also being tested to determine its characteristics.

Separate test burns were conducted in October, 1994, to assess air and ash emissions resulting from supplementing the normal clean, untreated woodfuel with five treated wood materials including: a combination of particleboard and plywood; creosote-treated utility poles; pentachlorophenol-treated utility poles; construction and demolition (C/D) wood waste; and chromated copper arsenate-treated (CAA) utility poles. In addition, ash from the combustion of clean, untreated wood normally used as fuel at the power plant was sampled and tested, consisting of both harvested wood and clean, untreated wood wastes such as mill residue.

The power plant is a simple-cycle steam facility with a multicyclone and an electrostatic precipitator. 12-hour composite ash samples were collected (except for CCA-treated wood, for which a 9-hour composite sample was collected). Composite samples consisted of both multicyclone and electrostatic precipitator ash. Bottom ash was not collected. During the test burns, treated wood was blended with the normal clean, untreated woodfuel in varying percentages, in order to provide the total heat input required for the boiler. The percentages of treated wood burned during the test burns are summarized below:

- Particleboard/plywood: 30.5% weight basis; 35.2% Btu basis.

- Creosote-treated wood: 29.0% weight basis; 32.4% Btu basis.

- Pentachlorophenol-treated wood: 27.9% weight basis; 32.0% Btu basis.

- Construction/demolition wood: 27.0% weight basis; 29.8% Btu basis.

- CCA-treated wood: 10.7% weight basis; 12.6% Btu basis.

Presented in Table 1 are the TCLP metal results for the six ash samples. Presented in Table 2 are the elemental metal, pH, and alkalinity results. The values reported are minimum and maximum test results for each composite sample. The regulatory limits reported in Table 2 are for Part 503 pollution concentration and ceiling concentration limits. Other chemical, physical, and environmental analysis results for both the ash samples and ash-concrete products that are being produced and tested will be analyzed and published later. Presented below are preliminary conclusions based on the results.

- Ash from the clean, untreated woodfuel, particleboard/plywood, creosote-treated wood, pentachlorophenol-treated wood, and C/D wood were below regulatory limits for the TCLP metals tested. This indicates the ashes will not be classified as hazardous waste under RCRA.

- CCA-treated wood ash exceeded the TCLP regulatory limits for arsenic, indicating the ash will be considered a hazardous waste. Although CCA-wood made up only 10.7% (wet basis) of the test burn fuel, the resulting ash exceeded the TCLP limits for arsenic by a factor of at least 26. This indicates that ash generated from woodfuels that contain even small amounts of CCA-treated wood may fail the TCLP.

- Of the six wood ashes analyzed, particleboard/plywood ash and pentachlorophenol-treated wood ash elemental metal concentrations were below Part 503 pollution concentrations for all metals tested. This indicates that in states that adopt Part 503 regulations for wood ash, these ashes could be land applied with limited or no regulatory oversight.

- Arsenic concentrations for untreated wood boiler ash tested in other programs range from 16.0 to 38.2 mg/kg. The clean, untreated wood ash generated during the test burns conducted for the NYSERDA study exceeded this range. The reason(s) are not known and this is not typical of other tests of clean, untreated woodfuel.

- Ash from creosote-treated wood, C/D wood, and CCA-treated wood exceeded the Part 503 pollution concentrations for arsenic. This indicates these ashes could not be land applied in those states that adopt Part 503 regulations for wood ash.

- The Part 503 ceiling concentration for arsenic is 75 mg/kg. Ash from clean, untreated wood and creosote-treated wood had arsenic concentrations below this value, indicating the ashes could be land applied, but with restrictions. Restrictions might include land applying at rates which do not exceed annual loading rates for arsenic and/or other metals.

- Ash from the C/D wood exceeded Part 503 ceiling concentrations for arsenic and lead. The ceiling concentrations for arsenic and lead are 75 and 840 mg/kg, respectively. This indicates the ash may be prohibited from being land applied, or might be permitted with restrictions, such as being land applied on a one-time only basis.

- CCA-treated wood ash exceeded Part 503 pollution concentrations for chromium and copper. It also exceeded Part 503 ceiling concentration for arsenic by a factor of at least 100. It is very unlikely the ash would be allowed to be land applied.

4. END USES FOR WOOD ASH

Presented in Table 3 is information on existing and potential end uses for ash from untreated and treated wood. The information is based on multiple surveys and interviews of wood ash generators and end users throughout the U.S.

Ash produced from the combustion of untreated wood has been used as a liming agent, source of potash, and nutrients on agricultural land for nearly a decade in several states. The amounts of carbonates, hydroxides, and high pH of wood ash can reduce soil acidity. The application of wood ash can improve agricultural productivity; improve soil conditions for growing turf, shrubs, trees, flowers, and other ornamentals; and may reduce the adverse impacts of acid rain. Other uses, such as sludge compost amendment, sludge odor control, and landfill cover, are expanding as landfill capacity becomes scarce and more expensive.

Existing end uses for ash from treated wood are limited due to concerns regarding contaminants that may potentially be in the ash. A potential large use for wood ash, and in particular treated wood ash, is as an admixture in concrete. Wood ash exhibits certain cementitious properties. When wood ash is combined with hydraulic cements (i.e. Portland cement), concrete products can be created with various compressive strength characteristics. The resulting ash-concrete product can potentially be utilized as either a low strength concrete or as "flowable fill". Flowable fill is a term that refers to a structural fill material that can be poured into place. An advantage of flowable fill over other structural fill materials is that compaction is not required. This reduces both the time and labor costs required to place the fill.

The combining of treated wood ash with cement may reduce, or eliminate, the potential for heavy metals contained in the ash (i.e. arsenic and chromium) to leach from the ash-concrete material. As hydraulic cement reacts with water (or hydrates), it forms a complex crystalline structure which can bind with or "tie up" metals, thus preventing their potential release. The high pH of ash combined with the lime content of cement also helps prevent the leaching of metals. This is because the metals are maintained in their insoluble hydroxide forms, rather than in their soluble elemental forms.

Potential end uses for low strength concrete include concrete fill for bridge or building decking, and cast concrete products such as road barriers, floor slabs, and concrete fill. Potential end uses for flowable fill include: fill around foundations; structural fill under concrete slabs and footings; structural fill in dams and bridge abutments; fill under or around pipes that are below grade; fill for utility cuts in roads; base material for sidewalks, parking areas, and low-traffic roads; and stream bank stabilization and erosion control.

5. RESOURCES FOR FURTHER INFORMATION

C.T. Donovan Associates, Inc. and BFI Organics, Inc. **Innovative End Uses for Wood Ash from Construction and Demolition Waste**. Final report to be prepared for the New York State Energy Research and Development Authority in Albany, New York in 1996.

Environmental Risk Limited, Inc. and C.T. Donovan Associates, Inc. **Wood Products in the Waste Stream Characterization and Combustion Emissions.** For the New York State Energy Research and Development Authority. Albany, New York. November 1992.

Definitions

In this paper, "untreated wood" is defined as wood that does not contain additives or chemicals such as harvesting residue, wood product industry waste, landclearing waste, stumps, and untreated dimensional lumber. Untreated wood also includes materials containing nails, bolts, and other items that can be removed. Pallets are generally considered to be untreated wood. However, some pallets are constructed with treated wood, are painted, or become contaminated during use.

"Treated wood" is defined as wood that contains additives or chemicals such as glues, resins, adhesives, preservatives, surface coatings, plastic, and laminates. Examples include plywood, particleboard, pressure-treated wood, and creosote-treated wood.

TABLE 1: TCLP METALS AND OTHER ANALYSES FOR ASH FROM TREATED WOOD (mg/l)

TCLP METAL	REGULATORY LIMITS	NORMAL WOODFUEL	PARTICLEBOARD/ PLYWOOD	CREOSOTE-TREATED	PENTACHLOROPHENOL-TREATED	CONSTRUCTION/ DEMOLITION WOOD	CCA-TREATED
Aluminum	N/A	0.06 - 0.09	0.5 - 0.6	0.3 - 0.4	0.5 - 0.7	0.3 - 0.5	0.4 - 0.6
Arsenic	5	0.07 - 0.14	0.16 - 0.21	0.19 - 0.20	0.28 - 0.38	0.66 - 0.78	131 - 224
Barium	100	1.1 - 1.5	0.5 - 0.8	0.7 - 1.0	1.1 - 2.0	1.3 - 2.0	0.8 - 1.3
Cadmium	1	<0.01	<0.01 - 0.01	0.02 - 0.04	0.12 - 0.14	0.05 - 0.09	0.01 - 0.02
Chromium	5	<0.02 - 0.2	<0.2	<0.2	<0.2 - 0.2	<0.2	<0.2 - 0.2
Copper	N/A	0.07 - 0.10	0.03 - 0.04	0.02 - 0.06	0.04 - 0.06	0.04 - 0.06	0.05 - 0.06
Iron	N/A	0.20 - 0.41	0.17 - 0.20	0.20 - 0.43	0.21 - 0.30	0.20 - 0.31	0.14 - 0.20
Lead	5	<0.1 - 0.1	<0.1 - 0.1	<0.1	<0.1	<0.1	<0.1 - 0.1
Manganese	N/A	7.9 - 13	12 - 13	15 - 20	29 - 31	22 - 23	3.9 - 5.2
Mercury	0.2	<0.002	<0.002	<0.002	<0.002	<0.002 - 0.002	<0.002
Nickel	N/A	<0.01 - 0.1	<0.1	<0.1 - 0.1	<0.1	<0.1	<0.1 - 0.1
Selenium	1	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
Silver	5	<0.1	<0.01	<0.1	<0.1	<0.1	<0.1
Zinc	N/A	0.03 - 0.06	0.22 - 0.30	0.23 - 0.56	0.90 - 1.79	2.5 - 4.4	0.04 - 0.05

TABLE 2: ELEMENTAL METALS ANALYSES FOR ASH FROM TREATED WOOD (mg/kg)

ELEMENTAL METAL	REGULATORY LIMITS	NORMAL WOOD FUEL	PARTICLEBOARD/ PLYWOOD	CREOSOTE-TREATED	PENTACHLORO-PHENOL-TREATED	CONSTRUCTION/ DEMOLITION WOOD	CCA-TREATED
Aluminum	N/A	4000 - 4500	4400 - 4800	3600 - 5000	3600 - 4200	4900 - 5800	3900 - 4500
Arsenic	41/ 75	42 - 53	22.5 - 26.9	51 - 64	24.3 - 27.7	78 - 98	8570 - 9390
Barium	N/A	220 - 300	280 - 400	200 - 280	220 - 270	480 - 590	220 -280
Cadmium	39/85	5.5 - 6.1	7.3 - 7.9	5.1 - 5.7	8.7 - 10.1	7.1 - 8.1	10.7 - 11.7
Chromium	1200/3000	12 - 14	12 - 15	14 - 17	19 - 23	34 - 39	1710 - 1850
Copper	1500/4300	41 - 46	50 - 59	49 - 52	52 - 61	71 - 93	2610 - 2820
Iron	N/A	5900 - 6100	3700 - 4300	14900 - 17100	5000 - 5100	6900 - 7400	6400 - 6900
Lead	300/840	29 - 35	73 - 78	47 - 50	198 - 235	920 - 1010	58 - 73
Manganese	N/A	2440 - 2750	2430 - 2740	2040 - 2140	2020 - 2230	2030 - 2230	2610 - 2720
Mercury	17/57	0.05 - 0.08	0.06 - 0.10	0.12 - 0.14	0.09 - 0.16	0.36 - 0.52	0.03 - 0.32
Molybdenum	18/75	5.6 - 6.7	7.6 - 8.2	4.0 - 5.4	4.8 - 6.1	6.9 - 8.0	8.6 - 11.4
Nickel	420/420	6 - 8	6 - 7	8 - 10	9 - 9	7 - 10	6 - 8
Selenium	36/100	0.53 - 0.69	0.55 - 0.64	0.74 - 0.81	0.55 - 0.65	0.84 - 0.97	1.18 - 1.45
Silver	N/A	0.2 - 0.4	0.3 - 0.4	0.4 - 0.4	0.1 - 0.2	0.1 - 0.1	0.7 - 0.8
Zinc	2800/7500	380 - 420	530 - 610	450 - 510	540 - 590	1420 - 1520	520 - 620
<u>OTHER</u> pH		11.31 - 11.67	10.64 - 10.85	10.69 - 11.09	10.18 - 10.39	10.76 - 11.12	10.68 - 10.84
Alkalinity (%)		12.0 - 13.2	13.4 - 14.6	10.2 - 11.6	9.1 - 11.3	11.7 - 12.5	11.1 - 12.2

TABLE 3: EXISTING AND POTENTIAL END USES FOR WOOD ASH

PRODUCTS	END USES	MARKETS
	UNTREATED WOOD ASH - EXISTING USES	
Agricultural liming agent	Increases soil pH	Sold or given to farmers
Fertilizer	Adds macro and micro nutrients to soil	Sold or given to farmers
Sludge compost amendment	Increases solids content of compost mixture	Sold or given to municipal or private compost facilities to replace sawdust or wood chips
	Odor reducing agent	
Charcoal binding agent	Charcoal production	
Landfill cover	Cover material for landfills	Direct or partial replacement for native soils
	UNTREATED WOOD ASH - POTENTIAL USES	
Water treatment	Clarifying agent for drinking water or other water	Replacement for clarifying agents
Wastewater adsorbent	Treatment of domestic and industrial wastewaters, including landfill leachate	
Liquid waste absorbent	Absorbent for liquid spills including gasoline and oil	As carbon content increases, absorbency increases
Hazardous waste solidification	Solidifies semi-solid hazardous wastes	Replacement for lime, clay, and cement kiln dust
Lightweight fill	Full in roadway bases, parking areas, and structures	Replaces other fine aggregates
Asphalt mineral filler	Fine aggregate in road asphalt	Use depends on gradation
Mine soil amendment	Added to coal and clay mine spoil to adjust pH	Amended spoil is used during mine reclamation
	TREATED WOOD ASH - EXISTING USES	
Road base aggregate	Fine aggregate in road base	Replaces fine aggregate
Landfill cover	Cover material for landfills	Direct or partial replacement for native soils
Filler in adhesives	Added to plywood adhesive to decrease the total amount of adhesive required	Filler in adhesives for wood products
Agricultural liming agent	Increases soil pH	Sold or given to farmers
	TREATED WOOD ASH - POTENTIAL USES	
Ash-concrete	Mixed with cement to produce low-strength concrete products	Replacement for concrete in low-strength applications

Prepared by C.T. Donovan Associates, Inc., 1995.

HARVESTING COTTON STALKS FOR USE AS A BIOMASS FEEDSTOCK

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Abstract

In Arizona, cotton residue left in the field following harvest must be buried, to prevent it from serving as an overwintering site for insects such as the pink bollworm. Most field operations to accomplish this are energy-intensive and often degrade soil structure, thereby increasing erosion and adding to particulate matter in the air. A system to harvest and transport this residue, instead of burying it, would be an economic benefit to cotton producers, and protect the environment as well.

A project underway at the University of Arizona since 1991 has led to the development of two systems for harvesting cotton plant residue. Stalks are first pulled with an implement developed for the purpose, and then baled using a large round baler, or chopped with a forage harvester and placed in a cotton module builder.

Density of the packages has varied, with the modules ranging from 168 to 252 kg/m^3 (10 to 15 lb/ft^3), and round bales from 93 to 168 kg/m^3 (6 to 9 lb/ft^3). Energy required per ton of material harvested has averaged 9.2 kWh/t (12.1 hp-hr/ton) for the baling system, and 8.6 kWh/t (11.4 hp-hr/ton) for chopping. Economics of the two systems are currently being evaluated. End use of the biomass, yield per acre, and distance from the field to the end use facility, will determine which system is optimal for a specific farmer.

Introduction

Cotton is Arizona's major crop, with more than 160,000 hectares (400,000 acres) planted annually, while total U.S. plantings exceed 4,400,000 hectares (11,000,000 acres). It has been estimated that the total amount of cotton crop residue produced in the United States exceeds 2.4 million tonnes (2.6 million tons) per year. The specific energy of cotton stalks compares favorably to that of wood, and as such could provide a valuable source of energy.

Under Arizona law, cotton plant residue must be buried, to prevent it from serving as an overwintering site for insect pests such as the pink bollworm. Most field operations used to bury the residue have high energy requirements, and tend to degrade soil structure, thereby increasing the potential for erosion. In addition, the intensive tillage operations used in this process increase particulates in the air, thereby decreasing ambient air quality. The residue is of little value as a soil amendment, and consequently is considered a negative value biomass. A commercial system to harvest cotton plant residue would provide both an economic and environmental benefit to cotton producers.

Project Description

The cotton stalk harvesting project commenced at the University of Arizona in the spring of 1991. Field evaluation of various implements began following the cotton harvest, and continued into January of 1992. During the summers of 1992, 1993 and 1994, the test equipment was modified, and additional equipment was obtained. Field evaluations took place following the 1992, 1993 and 1994 cotton harvests.

Over the duration of the project, numerous implements were evaluated to determine their potential for harvesting cotton stalks. The implements that have proven the most successful are described here. To facilitate presentation, these have been divided into three categories of operations: uprooting and windrowing, densification, and handling.

Uprooting and Windrowing

Two implements were evaluated to determine their effectiveness for pulling cotton plants from the soil:

1. Uprooter-Shredder-Mulcher (USM). This two row Israeli implement undercuts, then pulls the cotton stalks from the soil. After pulling, the stalks are conveyed by belts to a shear-bar cutter, where they are chopped and blown down a chute, placing the material below the soil surface. For this project, the USM was modified. The chute was replaced with a forage harvester spout, so that the chopped material could be blown into a trailing wagon, rather than being placed below the ground surface.

2. Cotton stalk puller. This implement was designed and fabricated for the project. The four row, self contained three-point hitch implement undercuts the cotton

stalks, then uses a pair of counter rotating pneumatic tires, which are hydraulically powered, to pull each row of stalks from the ground. The pulling action of the rotating tires, combined with the forward motion of the implement, causes the stalks to be thrown up and to the rear, where they are funnelled together by a pair of shields to form either one or two windrows on the soil surface.

Densification

Of the various types of equipment considered functionally suitable for cotton stalk densification, only the two judged most promising were evaluated:

1. Large round balers. These implements, developed for forage harvesting, collect the crop and roll it into a cylindrical form. Twine, wrapped around the outside of the bale, holds the bale together for later handling. Large round balers are manufactured in two sizes. The smaller units produce bales measuring 1.2 m (4 ft) long and 1.2 m (4 ft) in diameter, while the larger ones produce bales 1.5 m (5 ft) long, and 1.8 m (6 ft) in diameter. Both sizes were evaluated during the trials to compare energy efficiencies.

2. Cotton module makers. These implements produce large, relatively dense packages of harvested seed cotton, which then can be easily transported. They typically produce modules measuring 2.1 m (7 ft) wide, by 2.2 m (7.5 ft) high, and up to 9.6 m (32 ft) in length. Half length modules made from chopped cotton stalks were evaluated during the study. Several were made with material chopped by the USM, set to a theoretical length of cut of 35 mm (1.40 in). Additionally, modules were made from material chopped using a pull-type forage harvester set either to a theoretical length of cut of 28 mm (1.125 in) or 38 mm (1.5 in). In all cases the chopped material was transported to the module maker using a high dump wagon. Compression (ie. densification) of the module was obtained using the module maker's hydraulic system, powered from a tractor PTO.

Handling

Large and small round bales were loaded onto trailers and trucks using either tractor-mounted front end loaders or forklifts. These, and other devices specifically designed for handling baled materials, are commercially available. A truck-mounted cotton module mover was used to load and transport the modules. The modules generally retained their integrity through the loading, transport and unloading processes, though somewhat less stable packages resulted with the shorter lengths of cut.

Results

Biomass yield

Moisture content of the harvested cotton stalks ranged from 23.3 to 41.4 percent over the four year test, with an average value of 34.9 percent recorded. Biomass yields varied with harvest method, and from year to year. The variation from year to year was due to crop variety, as well as the length of time that had elapsed from picking to stalk harvesting. As time increased, yields lessened since more leaf material was lost, and the plants became brittle, causing some branches to be broken off and lost. The mean values recorded for each system, for each year in which it was operated, are shown in Table 1 along with the mean values obtained by hand harvesting several 3 m lengths of row in the same field.

Table 1. Biomass Yield.

Year		USM		Baling		Forage Harvester		Hand Harvest	
		kg/ha	lb/ac	kg/ha	lb/ac	kg/ha	lb/ac	kg/ha	lb/ac
1991	As Harvested	6166	5501	4987	4449		----		
	Dry Matter*	4014	3581	3247	2896		----		
1992	As Harvested	4013	3580	3990	3560	4125	3680		
	Dry Matter	2354	2100	2368	2113	2600	2320	4197	3744
1993	As Harvested		----	4148	3700	6017	5368		
	Dry Matter		----	2533	2260	3982	3553	5709	5093
1994	As Harvested		----		----	5650	5040		
	Dry Matter		----		----	3901	3480	4604	4472
Mean	Dry Matter	3184	2840	2716	2423	3495	3118	4604	4108

* estimated using the average dry matter content

From Table 1 it can be determined that in 1992 the USM, baling and forage harvesting operations recovered 56, 56 and 62 percent of the material harvested by hand. In 1993, the baling and forage harvesting operations recovered 44 and 70 percent respectively, while in 1994 the forage harvester recovered 76 percent. Each year, the forage harvester recovered the greatest percentage of stalks available, with the percentage increasing from year to year. The increasing rate of recovery was due to improved operating procedures, as well as due to improvements made to the equipment.

Weights and Densities

Each bale, and each load of chopped material that went into a module, was weighed at harvest. In addition, many of the modules and bales were weighed following several weeks of field storage. This information, when combined with dimensional measurements of the various packages, was used to calculate average package density at harvest, and following storage. (Table 2) The greatest module density was recorded for those made using the forage harvester. In comparing the baler data, it can be seen that the smaller bales provided the greatest density. This value, however, was considerably less than that of the modules.

Table 2. Average Weight and Density of Modules and Bales at Harvest, and after Storage in the Field.

System	Weight				Density			
	Harvest		Stored		Harvest		Stored	
	kg	lb	kg	lb	kg/m^3	lb/ft^3	kg/m^3	lb/ft^3
Modules								
USM	3574	7863	3786	8330	169	10.5	179	11.2
Forage harvester	5280	11617	5261	11575	232	14.5	235	14.7
Bales								
Small (2 rows)	220	485	145	320	138	8.6	98	6.1
Large (2 rows)	444	978	343	755	110	6.9	85	5.3
Large (4 rows)	371	817	280	616	98	5.8	30	4.3

Length of Cut and Energy Requirements

The distribution in length of cut produced by the USM and forage harvester, each set to two theoretical lengths of cut, are shown in Table 3. When set to approximately the same theoretical value, that is the USM to 35 mm (1.38 in) and the forage harvester to 38 mm (1.5 in), the distribution is quite similar. This is as expected, since the cutting mechanism in both machines is essentially the same. The forage harvester provided a maximum 38 mm (1.5 in) theoretical length of cut, without modification or utilization of non-stock parts. The USM was capable of providing lengths of cut up to 140 mm (5.5 in). The USM's much longer average cut length would produce modules much less subject to damage during the loading and unloading processes.

Table 3. Length of Cut Distribution, in Percent, Produced by the USM and Forage Harvester.

Fraction by median length		USM		Forage Harvester	
		35 (1.38)*	70 (2.76)*	28 (1.125)*	38 (1.5)*
mm	(in)	%	%	%	%
Trash	Trash	9.02	9.83	10.34	11.68
13	0.5	20.01	4.16	29.87	14.62
51	2.0	57.57	42.86	42.32	61.02
102	4.0	7.68	34.76	9.13	8.12
152	6.0	4.37	2.86	4.78	2.17
203	8.0	0.86	2.26	1.03	0.43
229+	9.0+	0.00	2.72	2.06	0.98

* Theoretical length of cut - mm (in.)

Energy required by the two implements should increase as length of cut decreases. In a series of trials conducted in 1992, the USM and forage harvester were operated in the same field, with the length of cut varied from the minimum to the maximum. For the USM, the theoretical lengths of cut were 35, 70 and 140 mm (1.4, 2.8 and 5.5 in). Power-take-off (PTO) energy required for the cutting operation was 19.8, 18.2 and 17.0 kW (26.6, 24.4 and 22.8 hp), respectively. For the forage harvester set to theoretical lengths of cut of 9.5, 19 and 28 mm (0.375, 0.75 and 1.125 in) PTO power averaged 9.5, 7.4 and 7.8 kW (12.7, 10.0 and 10.5 hp), respectively. The chopping energy required by the USM decreased as length of cut increased as was expected, whereas for the forage harvester the energy decreased, then remained approximately the same for the two longer theoretical lengths of cut.

Soil Contamination

Soil collected with the cotton stalks was measured to quantify contamination within each system. The USM modules averaged 3.3 percent soil by weight on a dry basis (range 3.1 to 7.7 percent), while the forage harvester modules averaged 2.4 percent (range 0.9 to 3.6 percent). The USM would be expected to retain more soil than the forage harvester since the plants are pulled, immediately chopped and placed in the module. Material collected with the forage harvester is handled twice, with the second operation taking place when the soil on the roots is drier, and hence more easily dislodged.

The bales contained significantly less soil than the modules. This is as expected, since the tumbling action inside the bale chamber knocks soil from the roots, then allows it to fall to the ground. The small bales averaged 0.57 percent soil contamination, while the large bales averaged 0.62 percent.

Since high soil content in the modules was a concern, a series of trials was conducted in 1994 to determine if this could be reduced mechanically. In addition to the control treatment of pulling the stalks and then chopping with the forage harvester, some windrows were passed through a conditioner immediately following pulling, and others 24 hours following pulling. After pulling, or pulling/conditioning, the stalks were chopped with the forage harvester and samples were taken from the wagon. Soil content in the unconditioned material averaged 1.39 percent, while the material that was conditioned immediately following pulling averaged 0.50 percent, a significant reduction. Waiting 24 hours prior to conditioning further reduced soil content, to an average value of 0.38 percent.

Energy Requirements and Field Capacities

Energy required by each of the harvesting operations was measured at the tractor-implement interface. The mean values are presented in Table 4, along with the operating speeds and field efficiencies that were determined through a series of time studies. In all cases the values are considered to be those which would be achievable under commercial conditions, and are not necessarily the highest or lowest figures recorded.

Table 4. Energy Requirements, Field Efficiencies and Capacities for the Various Harvesting Operations.

Method	# rows	Travel Velocity		Theoretical Capacity		Field Effic.	Effective Capacity		Energy		Energy*	
		km/h	mph	ha/h	ac/hr	(%)	ha/h	ac/hr	kWh/ha	hp-hr/ac	kWh/t	hp-hr/t
Puller	2	6.4	3.8	1.3	3.1	81	1.0	2.5	23.8	12.8	5.5	7.3
	4	5.1	3.1	2.0	5.0	81	1.6	4.0	34.6	18.1	5.4	7.2
USM	2	4.6	2.7	0.9	2.2	80	0.7	1.8	43.4	23.3	11.6	15.3
Forage	2	3.1	1.9	0.6	1.5	80	0.5	1.2	24.1	13.0	5.4	7.1
harvester	4	2.8	1.7	1.1	2.7	80	0.8	2.1	17.5	9.4	3.2	4.2
Baler Small	2	3.4	2.1	0.7	1.7	86	0.6	1.4	16.3	8.8	3.7	4.9
Baler Large	2	2.4	1.4	0.5	1.2	80	0.4	0.9	23.3	12.5	5.3	7.0
	4	2.5	1.5	1.0	2.4	81	0.8	2.0	19.3	10.4	4.2	5.5
Module maker	-	-	-	-	-	-	-	-	2.2	1.2	0.4	0.5

* Based on field moisture content

To allow comparison between the USM and the forage harvester systems, the energy required for pulling stalks must be added to the chopping energy required by the forage harvester. Thus the energy for harvesting on an area basis is 47.9 and 52.1 kw-hr/ha (25.8 and 27.5 hp-hr/ac) for two and four rows, respectively. On a weight basis the values are 10.9 and 8.6 kw-hr/t (14.4 and 11.4 hp-hr/ton), respectively. These are less than the USM.

The most energy efficient baling process, on either an area or weight basis, was found to be the small baler collecting two rows of pulled stalks. The least efficient operation was the large baler harvesting two rows.

The USM provided the greatest theoretical field capacity, of the two row collection operations. Considering that the USM provided a once over harvest, its competitive performance was further enhanced. For the other systems, two operations were required to harvest cotton stalks, that is pulling followed by either baling or chopping. Pulling, followed by baling, yielded a theoretical field capacity for the system of 0.50 and 0.64 ha/hr (1.26 and 1.61 ac/hr) for the small and large balers respectively, using a single tractor to power both the puller and baler sequentially. The theoretical field capacity for the forage harvester system would be 0.70 ha/hr (1.75 ac/hr). All these values are considerably less than those of the USM.

Several harvesting scenarios are possible, so energy requirements were estimated for the systems having the most potential for commercial use, by adding together the energy required by the individual operations comprising each system. The results are shown in Table 5.

Table 5. Energy Required, Density, and Energy/Unit Density for Various Harvesting Systems.

System	Energy		Energy		Density*		Energy/Unit Density	
	kWh/ha	hp-hr/ac	kWh/t	hp-hr/ton	kg/m³	lb/ft³		
Pull 4 rows - small baler	50	26.8	9.2	12.1	145	9.0	0.06	1.38
Pull 4 rows - large baler	50	26.7	9.4	12.4	92	5.8	0.10	2.15
USM-module maker	43	23.3+	11.6	15.3+	168	10.5	0.07	1.45
Pull 4 rows - forage harvester- module maker	51	27.5+	8.6	11.4+	230	14.4	0.04	0.75

+ does not include energy for transporting stalks to the module maker, or for unloading the dump wagon
* density of the material at the time it was placed into storage

It can be noted from Table 5 that the <u>most efficient system</u>, from the standpoint of energy required/unit density, is for modules made from stalks which are pulled, combined into a windrow made up of four rows of cotton stalks, and then chopped using a forage harvester. The <u>most inefficient system</u> is the larger of the two round balers. On the basis of energy per unit weight of material harvested, the two baler systems are comparable, with the USM requiring slightly more energy and the forage harvester slightly less.

Insect Emergence

Insect emergence from the stored material was a concern, since it is conceivable that insects could overwinter in the bales and modules and emerge in the spring. This would have the same theoretical result as insects emerging from improperly buried material, with increased insect infestations arising the following year.

To determine the extent of the problem, cages large enough to enclose either a half-module or several bales were made from window screening. The cage roofs were inclined and collection jars, normally used in field cage studies to trap pink bollworm moths, were installed at the upper corners of the cages. A Pheromone lure was placed in each of the collection jars, and pink bollworm counts made every two weeks, followed by lure replacement. The study was conducted using the 1992 and 1993 crops, and is currently underway for the 1994 crop. Table 6 summarizes the results of this study.

Since pink bollworm larvae cannot live at temperatures beyond 37 C (125 F), one of the 1993 modules was covered in black plastic in an attempt to increase its internal temperature. Thermocouples placed inside the module showed this not to be the case, with the temperatures for the covered and uncovered modules remaining approximately the same throughout the summer storage period.

Table 6. Insect Emergence from Stored Cotton Stalks.

Year	Storage Method	Date of Test	Number of Insects	Pounds of stalks/moth
1992	4 small bales	4/09 - 7/23	59	30
	6 small bales		13	208
	half module		37	300
1993	6 small bales	4/01 - 8/18	5	540
	half module		0	--
	half module*		3	3700

* covered with plastic

Combustion Tests

Studies have shown that the specific energy of cotton stalks ranges from 17.1 to 18.1 MJ/kg (7350 to 7800 BTU/lb) and compares favorably to wood at 17.4-18.6 MJ/kg (7500 to 8000 BTU/lb). (AR Systems, 1994) To determine the specific energy of the cotton stalks harvested during the project, samples from small bales and modules harvested in various years were sent to a commercial laboratory for proximate and ultimate analyses.

On a dry basis, the thermal output of the bale samples was 19.1 and 18.7 MJ/kg (8216 and 8055 BTU/lb), with ash contents of 4.2 and 4.0 percent for the 1992 and 1993 harvests, respectively. The thermal output for the modules made from the 1992, 1993 and 1994 crops were 17.8, 18.7 and 18.3 MJ/kg (7668, 8039 and 7883 BTU/lb). Ash contents were 10.4, 4.9 and 6.8 percent, respectively. Overall the samples averaged 18.6 MJ/kg (7983 BTU/lb) and had an ash content of 5.9 percent.

Summary and Conclusions

Based on the results obtained, it would appear that several harvesting systems are commercially suitable. The puller and small baler, or the puller and forage harvester appear most promising.

Although the USM works well and is commercially available with the exception of the discharge spout, its high initial cost combined with its high maintenance make this system less than ideal. Clearly, uprooting and chopping the stalks in a combined operation is superior to a two pass process. A possible means of obtaining such a system would be to modify the puller to allow a forage harvester to be drawn directly behind it. This would reduce system complexity as compared to the USM, and should also provide a more efficient method of harvesting cotton stalks.

The module system produced a denser package than the bales, and hence would lessen transport costs. In addition, loading a module is relatively easy using a truck mounted module mover. This is an additional advantage as compared to bales which must be individually loaded and stacked on a trailer for transport to an end use facility.

References

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RESOURCE MAPPING AND ANALYSIS OF UK FARM LIVESTOCK MANURES
- Assessing the Opportunities for Biomass-to-Energy Technologies

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Abstract

Livestock farms produce wastes with a high potential for pollution. Alternative, environmentally acceptable disposal routes might lie in biomass-to-energy schemes, generating revenue from the energy produced and fertiliser as a by-product; these are currently being developed, or assessed, for the UK under DTI/MAFF collaborative programmes; two options are being considered - direct combustion (12-14MW_e) and centralised anaerobic digestion (0.1-1MW_e CHP).

One of the barriers to initiating such schemes is establishing where feedstocks are located in order that they may be exploited in a cost effective manner. Resource mapping and analysis using a Geographical Information System has been used to establish the opportunities for England and Wales. This work was carried out in two parts:

- Produce spatially distributed resource data, of agro-industrial wastes and farm livestock manures, expressed in tonnes dry solids, from which energy production figures were derived.
- Develop algorithms to establish how much of this resource could be feasibly exploited.

By comparing these resource data with other appropriate information (e.g., road networks, environmentally sensitive areas, grid interconnections), the optimum location and size of potential biomass-to-energy plants were determined. Whilst interest in such schemes is anticipated to grow further over the next few years, their future will be heavily dependent upon the level of concern for wider environmental issues.

Background

The Resource

Livestock farms produce wastes with a high potential for pollution. Approximately 1.8 million tonnes (air-dried basis) of poultry waste (used litter and excreta) and some 14 million tonnes of livestock slurry (pig and cattle) are produced in the UK each year [1]. Traditionally, their disposal has been by direct use as fertilisers; in some instances these methods can cause environmental problems, such as odour and water pollution. Alternative, environmentally acceptable disposal routes with potential financial benefits might lie in biomass-to-energy schemes, which often provide fertiliser as a by-product.

Technical Options

Although a range of technologies is available, the choice of technology depends on the characteristics (primarily moisture content), geographical location and local concentration of the feedstock, and the climatic conditions (if solar drying is being considered). There are currently only two options being seriously considered in the UK [2].

- Where the moisture content is sufficiently low, as in the case of used poultry litter, direct combustion to raise steam to drive turbo-alternator sets may be employed. This will generate revenue both from the energy produced and from the ash by-product as a P/K (phosphate and potash) fertiliser [3].
- If the moisture content is high, then anaerobic digestion (AD) may be employed. This produces a biogas that may be burned in a gas-engine/generator set, a liquid fertiliser and a fibre that may be used as a soil conditioner.

Resource Mapping of Renewables

One of the barriers to the utilisation of farm livestock manures as an energy source is establishing where they are located in order that they may be exploited in a cost effective manner. As with many renewable resources there is no control over their geographical location so it is necessary to determine whether they may be economically exploited, given the circumstances in which they are found.

Within the National Biomass Programme, managed for Government by ETSU, there is therefore a need for resource mapping of farm livestock wastes to establish the potential for biomass-to-energy schemes. This paper outlines progress made to date and describes:

- The UK Strategy for deriving energy from agricultural animal wastes.
- Poultry population mapping as a means of identifying potential sites for poultry litter-fired power stations.
- How the resource mapping of farm livestock manures is being used to assess the likely opportunities for centralised anaerobic digestion.
- Future developments.

Combustion of Poultry Litter

Used poultry litter, a mixture of wood shavings (or straw) and droppings, is cleared from broiler houses where birds are raised for eating. It has a moisture content of about 20-30% and is well suited to combustion [3]. A number of appropriate combustion systems have been identified. The process results in the production of heat and/or power, and also a P/K rich ash. More widespread use is possible for this ash fertiliser as its smaller bulk allows for lower transport costs.

With the commissioning of two large-scale, poultry litter fired power stations (12-14MW_e), the UK has taken the lead in this area. Further schemes, up to 40MW_e, are also planned in which the poultry litter fuel may be supplemented with other biomass feedstocks (e.g., forest residues); benefits would still accrue from sales of the ash as a fertiliser, because the ash content of the wood component is both small (1%) and primarily composed of potash.

Commercial exploitation of such schemes has been assisted through the Non-Fossil Fuel Obligation (NFFO). Projects accepted under this scheme are guaranteed a premium price for their electricity for a pre-set period. In the long term, it is anticipated that renewables generation costs will decrease to meet increasing fossil-fuel costs, thereby making such technologies self-sustaining. It is important, therefore, to establish the opportunities for further schemes.

Centralised Anaerobic Digestion (CAD)

Experience with respect to on-farm AD in the UK has been poor as, for a number of reasons, plants have not performed to expectations [1]. There are opportunities for improving the economics through co-operative ventures at off-farm centralised anaerobic digestion (CAD) schemes (0.1-1MW_e CHP); this would be along similar lines to that carried out in Denmark [4]. These facilities would be fed primarily with farm wastes together with non-toxic, industrial organic wastes from food processing/preparation activities; these assist by not only providing another source of income (through tipping fees) but also through improving biogas yields.

The DTI (Department of Trade and Industry) and MAFF (Ministry of Agriculture Fisheries and Food) have therefore supported a collaborative strategy to establish the conditions under which CAD projects could be developed [1]. There are a number of reasons, however, why implementing such schemes in the UK would be more difficult. One of the difficulties is in establishing the location of sufficient quantities of farm yard manures and relating these to the industrial feedstocks.

Resource Mapping

Methodology

Resource mapping and analysis is being used to identify sources of collectable farm yard manure for England and Wales in order to determine the potential for biomass-to-energy plants. This work is being carried out in two parts:

- Produce spatially distributed resource data, of agro-industrial wastes and farm livestock manures, expressed in tonnes dry solids (tDS), from which energy production figures may be derived.
- Develop algorithms to establish how much of this resource may be exploited.

The methodology is based on using Livestock Census data, provided by MAFF, to derive livestock manure arisings. Whilst all farm sites are known from the census returns, the data are presented at the 'Parish' level so as to protect their anonymity. England & Wales are divided into about 11,000 Parishes, with distances between boundaries of about 2 - 4km; as transport distances to biomass-to-energy facilities are in the range 10 - 50km, data at this resolution are of value to resource estimation and project site location.

This approach, however, is subject to the following limitations:

- Only housed livestock are appropriate for this exercise since they produce animal wastes that are easily collectable.
- It is possible to overlook sites if new farming operations begin between Census's.
- Census returns not referring to the farm site may result in incorrect values being assigned to the Parishes.

Poultry Litter for Combustion

Waste products from rearing poultry either consists of urates and excrement, if the birds are kept in wire cages for egg production, or used litter, a mixture of droppings and litter (wood shavings, straw, etc.) if the birds are raised within heated poultry houses for meat production. Only used poultry litter is currently suited to combustion.

As the birds are typically reared on a 7-8 week cycle (chickens), some 7½ crops per year are possible. At the end of each cycle, the poultry houses are simultaneously emptied, disinfected, re-littered and restocked; whilst this is typical farming practice in the UK, in some countries (e.g., USA) the litter is often re-used for several crops.

A 12.6MW_e power station requires about 130 - 150kt/y of fuel; technology at this scale is therefore only appropriate where suitable concentrations of fuel occur. In several parts of the UK, large farms are located near meat processing and packaging plants. The fuel requirements are primarily dependent on the moisture content of the feedstock that varies due to differences in husbandry practices [5]. Farmers are therefore paid for this feedstock according to weight, moisture content and distance from the site.

Used-litter arisings are proportional to the number of birds; bird population maps were therefore produced to define areas of high feedstock density. The waste arisings from broilers, for example, are about 0.036kg/bird/day @ 70% dry matter [6]; the used-litter comprises of about 70% manure and 30% litter on a dry weight basis.

About, 1.4Mt of used litter is produced each year in England & Wales, with well-defined concentrations in East Anglia, Lincolnshire, the mid-south, Hereford and Worcester and the north-east; greater concentrations are also known to exist in the Humberside area, but because of the way the census data have been collected, these have not yet shown up in the current analysis [6].

Figure 1 shows a broiler population density map for East Anglia, based on June 1989 Census data for England & Wales; this clearly shows the reasoning for locating a 12.6MW$_e$ poultry litter-fired power station at the Norfolk/Suffolk border. The site is located on a dis-used airfield, close to the junction of two major roads. This area gives rise to approximately 350kt of used-litter, some 30% of the UK arisings, each year; about 50% is produced by broilers, the remainder by ducks, geese and turkeys which also show a similar spatial distribution around the project site. The power station requirements are about 40% of this resource, which is supplied within a 45km transport radius of the site.

This simple approach has highlighted the opportunities for several similar schemes in England & Wales. At present, there are two power stations in commercial operation, with contracts awarded for several more under the NFFO.

Centralised Anaerobic Digestion of Farm Yard Manures

Resource Assessment

When considering CAD, the transport and feedstock issues are more complicated in that several feedstock types, having different dry matter (DM) compositions, are involved. The DM content comprises primarily of organic material, referred to as the volatile solids, plus inorganic rubbish. Although biogas production is proportional to the volatile solids content, to a good approximation it may be assumed to be proportional to the DM content. Data are therefore produced on a tonnes dry solids (tDS) basis in order to put the different feedstocks on a comparable basis. Animal bedding (primarily straw) also influences the tDS produced; this can be digested but not to the same extent as farm livestock manures.

Factors were calculated to convert livestock numbers into waste dry matter for each class of livestock, and applied to Livestock Census data provided by MAFF [7]. These were based on the dry matter content and quantity of excreta produced, taking into account housing type, housing period (including regional variations) and bedding usage. This analysis was carried out for each livestock class at the Parish level, which were then summed into four main livestock groupings listed in Table 1:

Table 1: DM Content and Transport Distances for Each Main Livestock Grouping[1]

Main Livestock Groupings	Dry Matter (DM) Content (%)	Transport Distance (km)
Cattle & Sheep[2]	8-10	10
Pigs	10	10
Laying and Breeding Fowl (manure only)	30 (70)[3]	45
Broilers, Turkeys & Other Poultry (litter + manure)	70	45

[1] *Based on data from Reference 7.*
[2] *Some livestock within this grouping are only housed for 50% of the year.*
[3] *Figure in parentheses is achieved following partial air drying.*

Figure 2 shows a tDS map, plotted for each Parish centroid, for pigs in East Anglia. It highlights the high concentration of farming activity in an area of the country known as 'Rishangles Triangle', so called because outbreaks of nation-wide pig diseases usually first occurs here. The map clearly highlights the opportunities for CAD, with pig slurry as the primary feedstock.

There will be times during the year when certain feedstocks are not available; for example, some cattle groups in the UK are only housed for 6 months of the year. The blending of feedstocks to produce a balanced medium for the bacteria must therefore be practised to some degree, especially where feedstocks show seasonal availability. CAD facilities that rely on seasonal feedstocks must either compensate with other feedstocks or accept a reduced plant output for certain periods. The feasibility of developing a 'blending' model is currently being investigated under the National Programme.

Biogas Production

A CAD facility takes in many feedstocks that may vary in their efficiency to produce biogas; this is because the volatile solids composition (in terms of carbohydrates, fats and proteins) is not the same for all feedstocks. In the current model, however, it has been conservatively assumed that 1tDS of feedstock produces biogas containing $200m^3$ CH_4.

As the total energy content of $1m^3$ CH_4 is ~10kWh, the energy content of the feedstock therefore equates to about 2000kWh/tDS. If this gas is burned in a high-efficiency, gas-engine/generator set, this would produce $700kW_eh$ and $1000kW_th$. Excluding the in-house load leaves about $600kW_eh$ and $400kW_th$ available for export.

Analysis

The model calculates how much of this resource could realistically be aggregated for a CAD scheme. The location of the resource is tied into details of the road network system in order to establish the ideal location for a CAD plant that both minimise transport costs yet ensures maximum use of any energy generated. Figure 3 summarises the analysis in diagrammatic form.

Unlike feedstocks for combustion schemes, which are essentially of one type, the variable moisture contents of the different feedstocks for CAD schemes means that transport distances play an important role in determining both feedstock availability and plant location. The transport distance is based on their energy content; high DM feedstocks (~70%) may be transported from within a 45km radius of the site. Low DM feedstocks (~10%) are typically slurries, transported from within a 10km radius of the site.

Potential sites are analysed according to a search radius set according to a particular waste type and its ability to be transported. A buffer with a 10km radius is drawn around each Parish centroid for high moisture content feedstocks (pig and cattle). This will produce circles with a value equivalent to the volume of material available in that Parish. Where two circles intersect the value is the sum of the buffer circles. This was repeated for low moisture content feedstocks (poultry litter and poultry manure) using a 45km buffer. Again, intersections are the sum of the constituent parts. These two layers are combined to produce a dataset of material that is accessible from each point on the map.

Regions of high density were identified with their central point identified as a potential CAD site; this was to an accuracy of +/- 1km [8]. The total feedstock available for a potential CAD site was calculated and the energy potential assessed.

This was further refined by producing buffers around both the road and electricity grid networks and combining in a manner to show areas of high density within accessible distances to the grid network. Because pig and cattle slurries will probably be transported in 20m^3 tankers, only roads suitable for such vehicles were included in the analysis.

The results of an initial analysis have identified some 105 potential sites in England and 25 sites in Wales which would be suitable for schemes in excess of 1MW$_e$. In some regions there may also be the need to exclude environmentally sensitive areas, built-up areas, etc; about 20% of the potential sites identified fall within such environmental sites (Sites of Special Scientific Interest).

Conclusions/Future Developments

AD and combustion of farm livestock manures, as well as providing renewable energy, can also produce more environmentally acceptable residues which may be used as an alternative to inorganic fertilisers. Interest in such schemes is anticipated to grow further over the next few years, but their future will be heavily dependent upon the level of concern for wider environmental issues.

In order to exploit this resource cost-effectively, it is necessary to establish where these feedstocks are located. For large-scale, electricity-only schemes, this also means tying in with a suitable sub-station for connection to the grid. For CAD CHP schemes, the economics would be improved by fully utilising all the surplus heat. Unlike electricity generators, heat producers must establish themselves close to their customers, because the cost of the distribution network is more expensive and system losses much greater.

Draft algorithms for analysing spatially distributed biomass resource data have been developed and are currently being evaluated by testing them against known data held for one of the Regional Electricity Companies. The model will be further refined, and used to:

- Highlight areas where nitrate leaching could be a potential problem, with CAD or combustion providing a potential solution. Comparison with digitised ground-water and river water abstraction maps would highlight priority sites that might be at risk from contamination by farm yard wastes.
- Take into account competition for the CAD resource from combustion schemes.
- Identify potential heat market opportunities by overlaying the results against maps highlighting potential (primarily agricultural or industrial) heat users.

These results would assist the UK's National Biomass Programme in cost-effectively achieving its target for electricity generation from renewables.

The views expressed in this paper are those of the author and do not necessarily reflect those of the (UK) Department of Trade and Industry (DTI), Ministry of Agriculture Fisheries & Food (MAFF) or ETSU.

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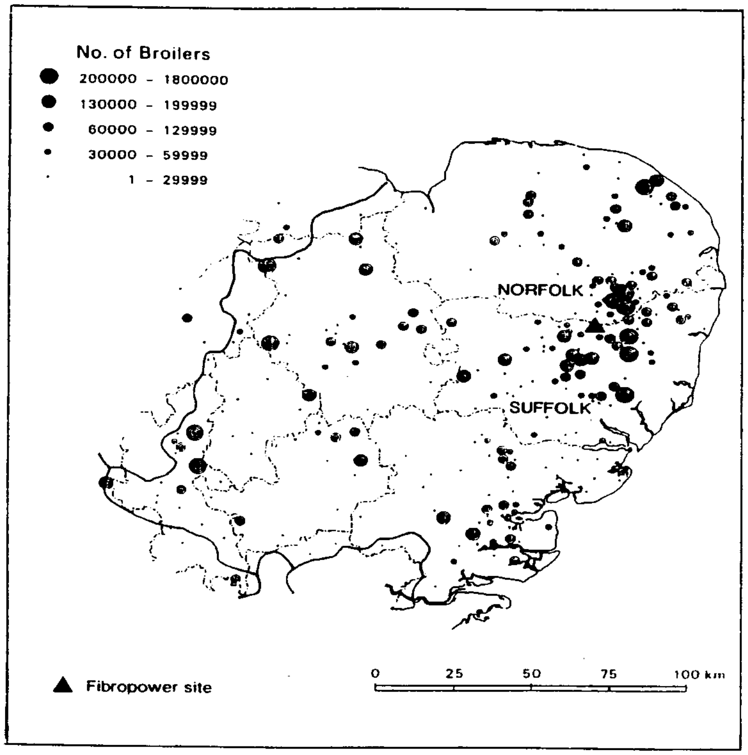

Figure 1: Broiler population at the Parish level - East Anglia

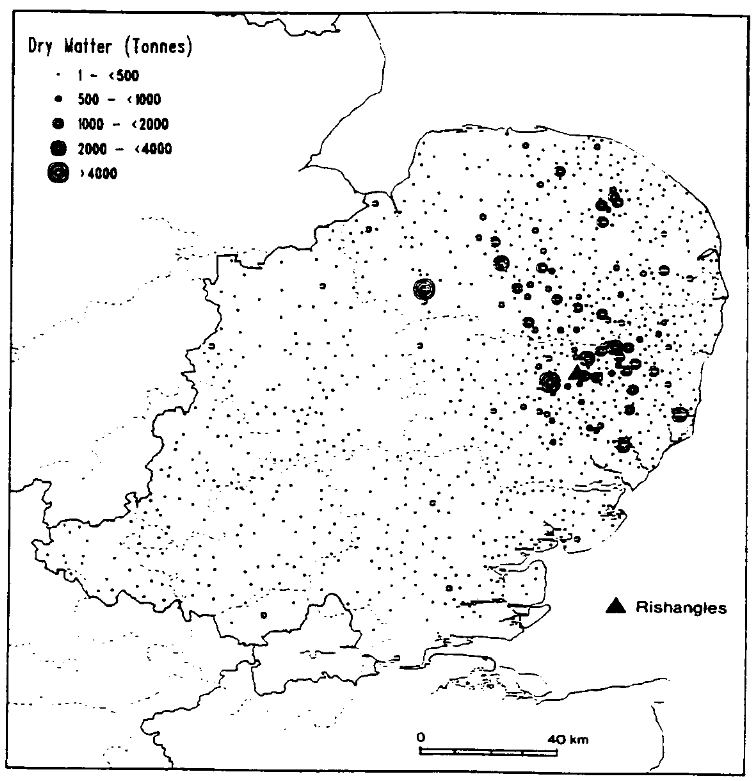

Figure 2: Pig manure arisings (tDS) at the Parish level - East Anglia

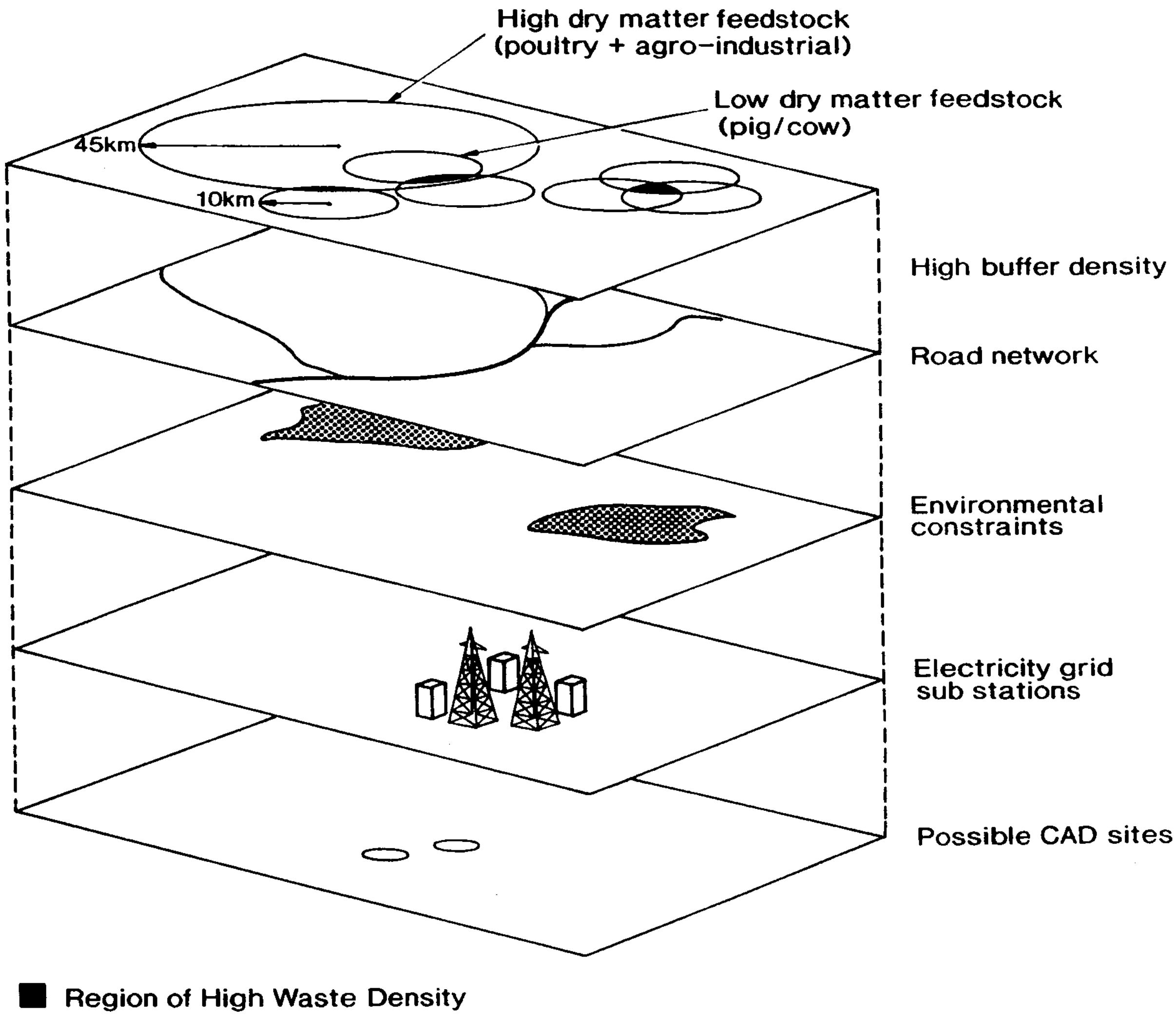

Figure 3: Overlay analysis - assessment of potential for CAD schemes

URBAN WOOD WASTE RESOURCE ASSESSMENT, THE STATE OF INDIANA

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Abstract

The purpose of this study is to quantify the wood waste resources produced on an annual basis within the state of Indiana. The project was developed in five steps. These steps included:

- Identifying the population of current wood waste generators in 11 metropolitan areas;
- Determining the annual volume of urban wood waste in the following categories: construction and demolition, tree trimmings and clearings, wood pallets, and primary and secondary wood processors waste;
- Identifying the current disposition of urban wood wastes and residues;
- Estimating the energy potential of urban wood wastes and residues; and,
- Identification of energy markets that may be appropriate for urban wood wastes.

The total estimated wood residue generated on an annual basis within these regions is 1.13 million bone dry tons per year with approximately 743,047 BDT/year available for use in the energy market, an equivalency of 398,000 tons of bituminous coal. Greater amounts are generated than are available because much of the "waste" is actually consumed for a variety of products including mulch, bedding, compost, and fuel. Based on information collected through this study, approximately 127,912 BDT/year of wood residues are presently consumed for energy purposes, either as space or process heat. This accounts for 1.9 trillion Btu/year, which is roughly equivalent to 68,000 tons of coal. If the wood residues produced and presently consumed for fuel by rural primary processors are added to the metropolitan figures, then there are approximately 3.3 trillion Btu of wood waste consumed for fuel purposes on an annual basis in Indiana.

The state of Indiana is endowed with considerable forest resources. The state's forests support a robust primary and secondary wood processing industry. Furthermore, there are other commercial and industrial sectors that process wood as part of their business activity. The wood wastes associated with these economic sectors have not been previously documented. This study provides information on the types, quantity, current disposal methods, and energy potential of urban wood waste in 11 defined metropolitan regions of Indiana.

Project Approach

The focus of this resource assessment is on urban wood residues in 11 metropolitan regions in Indiana. The regions encompass the largest populated cities in the state and their surrounding counties and account for approximately 80 percent of the state's population (see Table 1). The first step of the project was to identify all wood waste generators within each metropolitan region. These generator groups include: primary and secondary wood processors; pallet manufacturers and recyclers; the construction and demolition industries; and, urban tree and landscape residue generators. It is estimated that there are approximately 1,650 generators of wood waste in the state.

Table 1 Indiana Wood Waste Study Metropolitan Areas

Region Number	Name of Region	Population (1990)	Percentage of Total State Population
Region 1	Indianapolis	1,249,822	23%
Region 2	Fort Wayne	363,606	7%
Region 3	Evansville	339,481	6%
Region 4	Gary/Hammond	711,592	13%
Region 5	South Bend/Elkhart	403,250	7%
Region 6	Muncie/Anderson	298,467	5%
Region 7	Bloomington	267,281	5%
Region 8	Terre Haute	161,222	3%
Region 9	Kokomo/Marion	265,375	5%
Region 10	Richmond	97,966	2%
Region 11	New Albany	226,686	4%
TOTAL		**4,384,748**	**80%**

The resource assessment portion of the project required the use of three different data collection efforts. Telephone surveys were used to acquire data for the secondary wood processors industries, including pallet manufacturers and recyclers. Mail surveys were used to collect data on urban tree residues produced by the following generators groups: municipal park and recreation departments; municipal tree care divisions; county tree care divisions; electric utility power line maintenance; landscape maintenance/ landscaper /nursery firms; and, excavator/land clearance firms. The third data collection effort involved estimating the urban wood waste generated by construction and demolition industries. It was determined that construction and demolition industries do not maintain accurate records of wood waste production from their operations. Due to this inadequate data, national data were used regarding wood waste produced by building construction starts and demolition permits (and construction starts) issued in Indiana to estimate the wood waste generated by these two sectors. Data for all generator groups were obtained on a county-by-county basis and were aggregated to the 11 metropolitan regions defined by the state of Indiana Department of Commerce.

Project Results

In all 11 metropolitan regions, there are an estimated total of 1.13 million BDT/yr. wood waste generated and 743,047 BDT/yr. available (see Table 2). Greater amounts are generated than are available because much of the "waste" is actually consumed for a variety of products including mulch, bedding, compost, and fuel. Region 1, Indianapolis, generates the greatest amount of wood wastes and accounts for 26 percent of the total quantity available. Urban tree and landscape residues represent the single largest generator category for available wood wastes, 55 percent of the state total. The second largest generator group is Construction and Demolition which generates approximately 23 percent of the annual available total. Figure 1 illustrates the distribution of total wood waste available by county within each metropolitan region for the state of Indiana.

Table 2 Available Wood Waste by Indiana Generator Group (BDT/yr.)

Metropolitan Areas	Secondary Wood Processors	Pallet Manufacturers and Recyclers	Urban Tree and Landscape	Primary Wood Processors	Construction and Demolition	Total BDT Available
Region 1	16,139	5,159	116,075	5,046	46,891	189,310
Region 2	5,255	10,582	33,769	1,054	25,816	76,476
Region 3	11,447	5,919	31,529	3,559	11,450	63,904
Region 4	6,568	1,102	66,088	370	10,255	84,383
Region 5	19,892	1,650	37,451	2,706	33,324	95,023
Region 6	3,566	27,826	27,720	85	13,101	72,298
Region 7	4,879	2,238	24,823	7,512	5,785	45,237
Region 8	938	1,023	14,973	3,570	4,878	25,382
Region 9	2,440	2,255	24,646	1,315	2,712	33,368
Region 10	1,689	0	9,098	13	4,609	15,409
Region 11	7,319	4,429	21,053	3,234	6,222	42,257
TOTAL	**80,132**	**62,183**	**407,227**	**28,465**	**165,043**	**743,047**

*The total may not equal the sum of the regional estimates due to independent rounding of regional estimates.

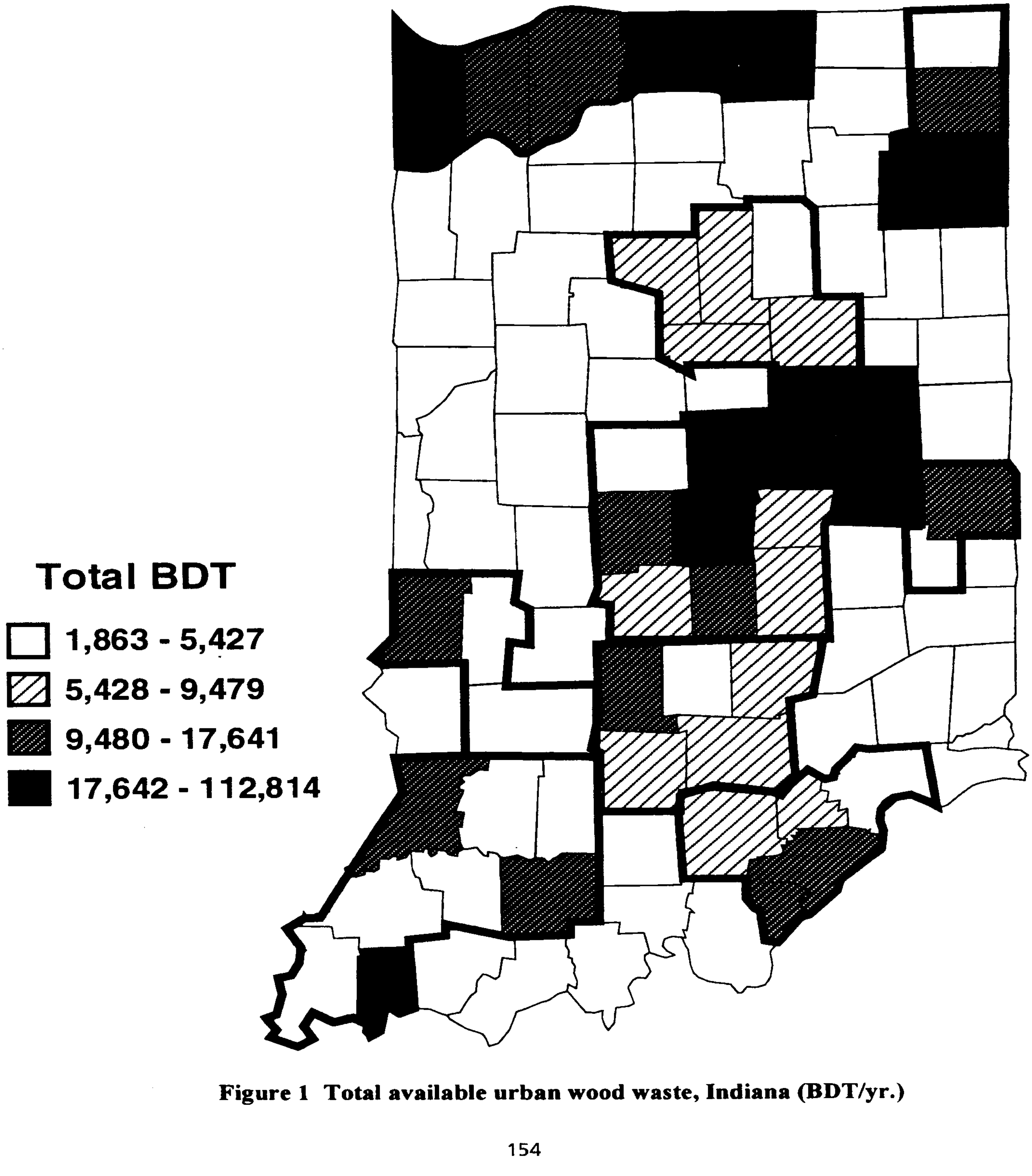

Figure 1 Total available urban wood waste, Indiana (BDT/yr.)

Energy Potential Summary

Based on information developed in this report, it is estimated that within the study area approximately 127,912 BDT/yr. of wood residues are presently consumed for energy purposes, either as space or process heat (see Table 3). These wood residues account for approximately 1.9 trillion Btu/yr. which is roughly equivalent to 68,000 tons of coal. If the wood residues produced and presently consumed for fuel by rural primary processors are added to the metropolitan figures, then there are approximately 3.3 trillion Btu of wood waste consumed for fuel purposes on an annual basis in Indiana.

Energy markets for wood residues are dependent on several factors including availability and seasonality of supply, quality of the residues, proximity of the residues to the end-user, prices for competing forms of energy, and institutional considerations. In Indiana, there are at least three distinct market niches for use of wood residues: (1) Co-firing of wood residues with coal in electric plants currently in operation; (2) Industrial co-fire and cogeneration at sites such as lumber mills, furniture plants, and other energy intensive locations; and, (3) Production of wood pellets, predominantly for the residential market.

Table 3 Application of Wood Wastes in Indiana

Category	Landfill	Sold	Fuel	Other	Total
Secondary	48,079	105,316	43,500	32,053	228,948
Pallets	36,346	58,706	14,768	25,837	135,657
UTR	6,343	10,204	4,604	418,377	439,528
Primary	N/A	N/A	65,040	126,255	191,295
C&D	N/A	N/A	N/A	N/A	330,087
TOTAL	**90,768**	**174,226**	**127,912**	**602,522**	**1,325,515**

N/A refers to not available.
*The total may not equal the sum of the regional estimates due to independent rounding of regional estimates.

The potential of wood residues to make larger contributions to the state energy balance is uncertain. Energy prices, market responses to environmental considerations, and government policies will all significantly influence the use of wood for fuel purposes. National trends suggest that the use of wood as an energy resource may increase in response to global climate change initiatives. Air emissions associated with combustion processes, specifically SOx, NOx, and CO2, may be reduced with greater use of wood-based fuels. However, with the exception of SOx emission trading allowances, it is difficult to establish a market price for the environmentally-beneficial aspects of wood fuels. Without true price signals, environmental aspects will only have limited influence on wood energy adoption by energy consumers.

Conclusions

The state of Indiana has considerable wood resources available for energy purposes. Large forested acreage coupled with a robust primary and secondary forestry/wood products industry results in the production of substantial wood wastes on an annual basis. Further, wood wastes produced as a by-product from construction and demolition activities or from tree maintenance operations also make substantial contributions. It is estimated that approximately 743,047 BDT/yr. of wood wastes or the equivalent of 398,000 tons of bituminous coal are available in the 11 metropolitan regions in the state.

Historically, wood residues in the state have been used for a variety of products in distinctive market niches including bedding material (e.g., for turkeys, horses, dairy cows, and swine), compost, mulch, and fuel for heating. Furthermore, a small wood pelletization market is beginning to emerge. Market infrastructure has been developed to purchase, distribute, and use much of the relatively higher value dry sawdust material. Market forces have established price/value relationships and a web of supplier/broker/buyer relationships exist.

However, a considerable volume of unused wood residues remain in the state. A large portion of these residues are landfilled. Because of the pressure to use landfill space effectively, disposal of "green" residues is of concern to the regulatory community, policy makers, and private or public organizations who create the residue. The unique nature of the wood residues poses both opportunities and challenges for productive use.

The potential of wood residues to make larger contributions to the state energy balance is uncertain. Energy prices, market responses to environmental considerations, and government policies will all significantly influence the use of wood for fuel purposes. National trends suggest that the use of wood as an energy resource may increase in response to global climate change initiatives. Air emissions associated with combustion processes, specifically SOx, NOx, and CO2, may be reduced with greater use of wood-based fuels. However, with the exception of SOx emission trading allowances, it is difficult to establish a market price for the environmentally- beneficial aspects of wood fuels. Without true price signals, environmental aspects will only have limited influence on wood energy adoption by energy consumers.

The major wood waste generator categories that are not presently used in the state, urban tree residues and construction and demolition by-products, have unattractive attributes for energy conversion. The UTR resource is produced as a by-product of tree-trimming operations. This residue stream has uneven fuel quality characteristics (e.g., chips of different sizes, logs, and brush). Such diversity limits the economic attractiveness because subsequent fuel processing is necessary. Further, the residue is produced by many generators at multiple locations. The wide-spread distribution of the wood wastes makes collection of the low-value fuel expensive and time-consuming.

Similarly, construction and demolition wastes have attributes that hinder their economic use as fuel. The primary drawback is the cyclical nature of the industry. Housing starts and demolition activity show wide fluctuations on an annual basis as the industry responds to local economic conditions. Security of fuel supply is important to an end-user and the construction and the demolition wood waste stream cannot deliver a guaranteed quantity of fuel on an annual basis. Further, some wood waste from this sector is contaminated with paints or other wood treatments that may be released into the atmosphere during combustion. Although there are several energy conversion processes that can mitigate this risk, the public perception issue is of concern to potential fuel users.

The use of biomass for energy purposes has been demonstrated to have positive economic, environmental, and social benefits in many states and regions. Such benefits have been realized in Indiana for a variety of firms who already use wood residues. It is likely that the use of wood waste for thermal energy will continue to be the most significant contribution in the state. Firms currently using wood for heat are unlikely to switch to another fuel mainly because they have already "sunk" their investments. Further, the introduction and growth of the residential wood pellet industry ensures that thermal demands for wood fuels will increase over the next several years.

Increased benefits may be possible in Indiana with greater usage of woody fuels, particularly wood wastes that are presently being landfilled. However, such benefits are unlikely to accrue to the state without marketplace changes that affect the use of biomass. The state may foster the development of the wood waste resource base through a number of steps.

State activities to further expand the role of wood energy may be considered in an incremental fashion. A range of activities may be considered. Information dissemination, scoping studies, technical assistance, demonstration projects, and regulatory actions are all possible courses of action.

Acknowledgements

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URBAN WOOD WASTE IN MICHIGAN: SUPPLY AND POLICY ISSUES

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Abstract

This study provides the most comprehensive and detailed non-proprietary assessment and characterization of urban wood waste (UWW) to date for Michigan and the U.S. Nine components of the UWW stream were quantified and analyzed by surveying 44 UWW haulers and processors and 19 urban wood foresters in the Detroit, Grand Rapids, and Lansing markets. The nine UWW components consist of 1) used pallets, 2) wood scraps, 3) construction debris, 4) demolition debris, 5) tree trimming residue, 6) land clearing wood waste, 7) plywood/particleboard waste, 8) used railroad ties, and 9) "other" wood waste. UWW is defined as wood residue generated by municipal, industrial, commercial, construction, and demolition sources, and includes pallets/dunnage, wood scraps, construction and demolition debris, railroad ties, tree trimmings, land clearing, plywood/particleboard, and other UWW component streams. Our final estimate of 593,395 tonnes of annually generated UWW compares with 781,630 tonnes of residue generated by Michigan's secondary wood manufacturing industry. Our study estimates that 90 MW of electric generating capacity can be produced from the UWW supply in our study area. Total electric power capacity is about 20,000 MW in the state. The UWW market was found to be highly dependent on used pallet generation (46% of total UWW). Current fuel demand by Michigan's wood burning power facilities is 1,530,360 TPY and will increase to 1,936,800 TPY as a major new facility comes on-line. Unless regulatory standards for "contaminated" wood supplies are relaxed, supply shortages may occur. Other significant end-markets for UWW compete for UWW supplies which may drive prices up. UWW markets and prices are extremely volatile, and they are extremely sensitive to various regulatory and market factors that are not always carefully considered nor understood.

Introduction

This study of urban wood waste began with a review of current literature about wood waste generation, disposal, and end-markets. This review provides an understanding of waste generation research methodologies and the corresponding quality of data. It also includes a brief overview of wood waste regulatory issues and the dynamic character of secondary wood waste markets.

Three survey instruments were designed to elicit data about the types and quantities of urban wood waste(UWW) generated in the Detroit, Lansing, and Grand Rapids markets. The three survey groups included solid waste and recycling coordinators, wood waste brokers and processors, and urban forestry and landscaping operators.

The first survey instrument was used as a guide for discussions with coordinators. In all cases, recycling and solid waste coordinators emphasized that they lacked even basic knowledge of urban wood waste types and their generation. They indicated that estimates in their county solid waste management plans, which are required under the Michigan Solid Waste Management Act (PA 641 of 1978), were arbitrary and unreliable.

Second, interviews were conducted with 44 of 50 firms in the study area that haul and process wood waste. A survey instrument, comprised of open- and closed-ended questions, served to guide the structured interview. The survey instrument was designed to elicit data about current and past UWW generation, future trends, processing capacity, and end-markets for UWW.

A third survey instrument was designed for interviews with urban forestry departments and landscaping operators. Nineteen interviews were conducted with personnel in city and county parks and forestry departments, university grounds departments, and utility tree trimming operations. Data collected with this survey augmented data about urban tree trimming residue which was underreported in the survey of haulers and processors.

The strength of the methodology used to conduct this study is that data generated from several sources can be compared and refined, thereby increasing the accuracy of our conclusions. It must be emphasized, however, that quantities of UWW estimated by respondents are self-reported. Moreover, the methodology used in this study did not allow for measuring quantities of UWW generated by small quantity generators who landfill or incinerate their UWW as part of their municipal solid waste(MSW) stream or who otherwise dispose of their own UWW.

"Clean" UWW refers to uncontaminated and untreated natural wood products and residue that are generated by a broad range of industrial, commercial, municipal, agricultural, construction, and demolition activities. "Treated" refers to chemical alteration of natural wood by binders, adhesives, preservatives, glues, resins, paints, stains, or coatings. Most "treated" wood currently does not have secondary end-market potential. The quantity of "treated" UWW is under-reported.

Literature Review

Urban Wood Waste Generation Estimates and Landfill Tip Fees

Estimates of urban wood waste changed substantially in reports published by the U.S. EPA in 1990 and 1992. According to the 1990 MSW characterization report, 5.9 million tonnes of wood waste were generated nationally in 1988, and none of it was recovered. The 1992 MSW characterization report substantially increased the estimate from 5.9 million tonnes to 11.1 million tonnes, or 7% of MSW in 1990. These estimates are based on National Wooden Pallet and Container Association data that indicate 536 million pallets were produced in 1990. Wood pallet production has steadily increased since 1990.

EPA reported a wood waste recovery rate of 3.3%, but this rate is limited to recovery for use by secondary markets for composting and mulch.

According to the National Solid Wastes Management Association, landfill fees continue to increase. Midwestern tipping fees, of $27.10 however, are below the national average of $30.21.

State Characterizations of Wood Waste in the Great Lakes Region

Four state reports published since 1991 assess some aspect of UWW generation, disposal, and markets. However, none provides an overall characterization of urban wood waste.

The Illinois Department of Energy and Natural Resources(IENR) investigated the feasibility of a landfill ban on wood waste, including construction and demolition (c/d) material. Of Illinois's estimated 1,411,223 tonnes of wood waste produced per year, 32.5% was landfilled. Only a small fraction of wood waste generated by primary wood producers was landfilled. This sector's wood waste was used for low value-added products such as fuel and animal bedding. Secondary manufacturers reported that 77% of their wood waste was reused as fuel, compost, or other wood product manufacture. These manufacturers were finding alternatives to landfilling because of rising tipping fees.

Estimating the amount of C/D disposed in landfills is difficult because it is commonly commingled with other waste streams. IENR estimated that C/D wood waste accounts for 40% of the total wood waste disposed of in landfills. IENR also used WastePlan, a solid waste computer model, to derive wood waste generation estimates of 225,000 and 31,163 tonnes for the commercial and residential sectors, respectively.

The 1993 *Wisconsin Wood Residue Study* identified the quantity, type, location, and disposal methods of the industrial wood residue stream as well as considering the potential for industrial development using wood residue. Results were analyzed by SIC code, forest survey unit, number of employees per firm, disposal method, and disposal cost. Wisconsin firms produced an estimated 1,936,841 tonnes of wood waste annually. Mid-size firms generated the most wood residue.

Pallet residue accounted for 119,700 tonnes annually, and non-pallet residue accounted for 1,817,100 tonnes. Possible uses for the wood waste stream included particle/inorganic bonded board, fireplace logs, molded products, fuel, pulp, animal bedding, and landscape mulch.

A survey of secondary wood manufacturing residue generation was published by the Forest Management Division of the Michigan Department of Natural Resources in March, 1994. The goal of the study was to facilitate the use of wood and paper residues as raw materials or energy sources.

The report identified location, volumes, and types of wood and paper residues produced by secondary wood manufacturers in Michigan and compared the amount of each type being landfilled to its potential as an energy source. Secondary wood products manufacturing is distinguished from primary wood products manufacturing in that it does not involve the harvesting of trees or using roundwood in its manufacturing processes.

Wood chips comprised the largest amounts of residue at 51.5% with sawdust the second largest waste stream at 22.7%. The primary means of disposal is use as fuel (68.3%) while recycling accounts for 24.2%. Only a small portion (.09%) was landfilled, but this portion represents an estimated potential of 6.3×10^9 MJ for all secondary manufacturing.

The 1992 *Urban Tree Residue* study by the Minnesota Department of Natural Resources estimated the generation of urban tree residue in the Twin Cities area. End use of this stream is important in light of a 1992 Minnesota ban on landfilling tree and shrub waste.

The Minnesota study found that approximately 50% of the 292,500 annual tonnes of urban tree residue was used, but only 14% generated any revenue. Of the 86% that did not generate revenue, 41% cost money for disposal. Six basic factors prevented marketing the residue successfully, including 1) Excess supply vs. weak demand (demand is only one-tenth of available supply); 2) Too few existing recycling sites and location problems with proposed expansions; 3) Lack of public information on the subject; 4) Low priority on wood residue recycling; 5) Absence of comprehensive public policy; and 6) Lack of active industry organization.

Urban Wood Waste Stream Components

This section analyzes and assesses data for nine components of the urban wood waste (UWW) stream based on our survey interviews with 44 UWW haulers and processors and 19 urban foresters. As no standard for collecting generation data of MSW, including wood waste, currently exists, it is our intent that this study will contribute to the formation and practice of sound protocols for gathering and analyzing waste generation data.

Key Definitions

Urban wood waste (UWW) is defined in this study as wood residue generated by municipal, industrial, commercial, construction, and demolition sources. The study focused on the three major urban areas of Detroit, Lansing, and Grand Rapids in southern Michigan. Generation estimates correspond to the location of the processing facility rather than the location of the UWW generator.

Developing Used Pallet Generation Estimates

The vast majority of the UWW hauling and processing market is in pallets: 93% of the respondents in the processors survey process or haul pallets. It is estimated that Michigan accounts for 5-8% of national pallet production.

The used wood pallet market is evolving rapidly, and competition in this market is intense. Of the 44 respondents to the processors survey, 29.5% were involved in the pallet reconditioning market and at least one respondent considers pallet reconditioning more economically appealing than the wood waste fuel market. Nearly a third, or 32%, of pallet processors recondition pallets *and* use unsalvageable pallets for fuel. Major contaminants include steel nails and bands, dirt, plastic shrink wrap, and corrugated cardboard.

Nearly three-quarters of survey respondents predicted increased volumes of pallets in the next three to five years, and 48% indicated that volumes had already increased in the past three to five years.

Used Pallet Generation by Market Area

Estimated annual pallet generation equals 270,738 tonnes. Hauling and processing capacity is being utilized at a rate of 72.3%. Detroit area processors have an annual capacity of 236,700 tonnes and currently utilize 69.8% of this capacity. The total quantity of used pallets in the Lansing area is 4,680 tonnes. The market for used pallets utilizes 57.1% of its capacity. Grand Rapids area processors haul and process 34,632 TPY to utilize 62.9% of the market capacity. Other markets utilize 88.6% of their capacity.

Wood Scrap Generation by Market Area

Wood scraps are the second most predominant UWW material in terms of the number of haulers and processors hauling this stream - 43% of respondents haul or process wood scraps. Annual generation is estimated at 52,416 tonnes and the capacity utilization rate was 62.5%. In the Detroit area, annual generation is estimated at 9,711 tonnes with a capacity utilization rate of 51.9%. The Lansing area generation is estimated at 5,850 TPY with a utilization capacity of 36.2%. Annual generation in the Grand Rapids area was estimated at 27,378 tonnes with a capacity utilization rate of 78.3%. Total annual generation in other southern Michigan market areas is estimated to be 9,477 tons with a utilization capacity of 67.5%.

Construction Debris Generation by Market Area

Construction debris and demolition debris were treated separately by the survey instruments because the physical characteristics of these two streams are quite different. Since demolition debris wood waste is often contaminated with lead-based paints, this material can pose a significant threat to human health and the environment. Demolition debris requires greater handling to separate materials than does construction debris.

The total annual quantity of construction debris processed and hauled was 81,549 tonnes yielding a capacity utilization rate of 34%.

Six Detroit respondents indicated that they hauled or processed a combined total of 162.5

TPD of construction debris. The total capacity of hauling or processing construction debris in Detroit was determined to be 872.6 TPD, yielding a capacity utilization rate of 18.6%. The Lansing area has a utilization rate of 60% with an annual generation of 702 tonnes while Grand Rapids generates 2,808 tonnes annually for a capacity utilization rate of 60%. Other southern Michigan market areas generate 35,802 tonnes of construction debris per year.

Demolition Debris Generation by Market Area

Only three respondents reported hauling and processing demolition debris. However, given regulatory concerns associated with this stream, the small number is not surprising. The total amount of demolition debris hauled and processed in the study area is 31,122 TPY. This figure underreports demolition debris. The utilization rate was 14.3%.

There was no reported hauling or processing of demolition debris by Lansing or Grand Rapids area haulers or processors. However, county solid waste staff indicated that the Lansing-based Daggett Sand and Gravel processes and sells as much of its demolition debris in secondary markets as possible to extend the life of its landfill.

Kent County solid waste management data indicated that wood makes up 6.4% of the waste stream, or 31,897 TPY. However, this percentage composition may be arbitrary.

Tree Trimming Residue Generation by Market Area

The Great Lakes States generated 2.1 million cubic meters of urban tree and landscape residue in 1993 according to a draft report by the International Society of Arboriculture (ISA). Nationally, commercial tree care firms and electric line maintenance account for 91% of the total national generation of this residue.

The total reported amount of residue hauled or processed in our market study area was 2,633 TPY (based on 260 days/year), and the utilization rate was estimated to be 83%.

The Lansing area market generated a total of 1,403 tonnes per year. Detroit Edison, the greatest single contributor to tree trimming residue, generated 29,761 tonnes. The City of Detroit is the next biggest generator with 14,940 tonnes.

Four factors affect generation of urban tree trimming residue data reporting, including budgetary constraints, scope of operation, jurisdiction, and measurability. Most jurisdictions reported chipping their residue and using the chips in their parks and playgrounds or in compost yards. Many disposal schemes included free public distribution of mulch.

Wood Waste Generation from Land Clearing

Twenty-four tonnes per day of land clearing wood waste are hauled by eleven percent of respondents. This component of the UWW stream is relatively more specialized and at the low value end of the market. Since stump removal is frequently part of land clearing, heavy-duty removal equipment may be needed. Contaminants are a problem for most secondary markets, but land clearing waste is an appropriate feedstock for composting.

Plywood/Particleboard Waste Generation
Eleven percent of respondents haul or process 9,945 TPY of plywood/particleboard for a utilization rate of 63%.

Used Railroad Ties
Approximately 750 million railroad ties are in the U.S. and Canada, and 1.6%, or 12 million, are replaced yearly. In Michigan, over 197,000 ties used for 3,994 commercial miles of track are replaced annually. However, the total number of railroad ties annually disposed is underestimated because short line track in not included. This estimate is based on annual maintenance; therefore, stockpiled inventories are also not included.

Nationally, 62% of used ties are sold to contractors, who then sell them to commercial landscapers or lumberyards. One-fifth of old ties are landfilled, 15% are sold to co-generation facilities, and 3% are stored. However, none of the staff interviewed as part of this study indicated that any used ties produced by their lines were landfilled.

We conservatively estimate that Michigan generates 267,000 ties, or 18,023 tonnes of ties per year. Determining the number of ties that are stockpiled is beyond the scope of this study, however, 67,500 tonnes may be a reasonable estimate. Transportation logistics and prohibitive shipping costs associated with transporting used ties to processing facilities limit their reuse.

Other Wood Waste Generation
Eleven percent of the processors surveyed haul or process other wood waste in addition to those categories listed above. Categories include sawdust, chips, and waferboard.

Wood Processing and Fuel Prices

More than 45% of respondents process their own UWW and 50% do not. Nearly 39% of respondent firms want to add equipment, particularly a tub grinder.

Thirty-four percent of respondents sell processed UWW to wood-burning facilities. Wood fuel prices range from $13 to $39 per tonne with price variations dependent upon supplier relationships, quality of UWW fuel, and transportation distances. In 1993, a 34-megawatt facility began operating in Cadillac. As a result, demand for UWW increased substantially, causing a surge in wood fuel prices to over $33 per tonne in early 1994.

Prices settled back down by summer of 1994, but it is plausible that prices will rise again from the current $22-25 when CMS Energy's Genesee facility begins operating in 1995. A processor established to supply UWW to this facility is currently buying UWW and stockpiling it. Some processors have speculated that the current pinch in supply already reflects the increased demand of the Genesee facility.

Finally, UWW prices would almost certainly increase dramatically if a proposed Detroit Edison venture to build a medium-density fiberboard (MDF) facility in Detroit is realized. This proposed plant would require over 90,000 tonnes of UWW per year and would have the of being located in the "urban wood waste forest."

Competing End-markets

Wood pallets are reconditioned and recycled by 30% of respondents and emphasized by at least 9% that pallet reconditioning is a higher value-added use for UWW than boiler fuel. The second greatest end-market use for UWW was landscaping, particularly as wood mulch, with 25% of respondents selling to this market. The future of the mulch end-market appears strong with the increasing emphasis on natural and organic approaches to gardening and landscaping.

Firewood was the third most commonly cited competing end-market use; 14% of respondents indicated participation in this market. The level of activity in this market was considerable - from commercial distribution of the product to giving it away on site.

Few respondents (9%) participated in three other end-markets: composting, recreational surfaces, and animal bedding. No respondents indicated participation in the composite wood market.

Issues and Conclusions

Regulatory requirements in Michigan for wood-fired electric generating facilities are very strict. Wood treated with any chemicals or wood contaminated by non-wood materials is not permitted for use as fuel because of the anticipated impact on toxic air emissions.

A test burn at the Viking Energy facility in McBain last September, provided data to evaluate the use of six fuel types, including 1) creosote-treated wood; 2) PCP-(pentachlorophenol) treated wood; 3) CCA-(chromated copper arsenate) treated wood; 4) particleboard/plywood; 5) construction/demolition (C/D) debris; and 6) tire-derived fuel (TDF).

It is expected that the facility's combustion temperatures and pollution control equipment will allow combustion of these materials without toxic emissions exceeding regulatory limits. Railroad ties and C/D debris are the most sizeable UWW streams that will be impacted by this test burn. State regulatory approval of C/D, railroad ties, and other "treated" wood types as fuel would clearly increase the amount of available UWW supply.

Proposed Amendments to the Michigan Solid Waste Management Act

Flow Control

Flow control refers to the intent of jurisdictions to assure compliance with solid waste regulations by controlling volumes of waste by designating the location of their disposal. Under the Michigan Solid Waste Management Act, counties are required to explicitly authorize movement of solid waste between counties. In most respects, however, changes in solid waste flow control will not directly impact the UWW market.

Data Requirements

Data reporting requirements for solid waste management plans may be upgraded, although the generation of quality data is stymied by the lack of a uniform data collection methodology. Absence of reliable waste stream characterization and volume data seriously hinders efforts to encourage greater use of wood waste for fuel and other value-added applications. Difficulties in gathering quality data include issues of proprietary market and processing information, the diverse methods of collection and hauling, and diversity of end-points for waste/recycled materials.

Conclusions

The constant interplay of regulatory issues, UWW generation, the need for electric generating facility fuel, and other competing end-markets creates a rich matrix of interdependent factors affecting the demand for and prices and supply of urban wood waste.

Our final survey estimate of 593,395 tonnes of urban wood waste annual supply in this market study area compares with estimates of 456,300 tonnes of C/D waste in the 1991 Illinois study, 2.0 million tons of wood waste and 119,700 tonnes of pallet residue in the 1993 Wisconsin study, 292,500 tonnes of urban tree residue in the 1992 Minnesota study, and 781,630 tonnes of wood waste generated by Michigan's secondary wood manufacturing sector. It is likely that some overlap exists between our study and the secondary manufacturing study. Our study estimates that 90 MW of electric generating capacity can be produced from the UWW supply in our study area. Total electric power capacity is about 20,000 MW in the state. By disaggregating the urban wood waste stream into nine components we have established a level of detail not previously achieved in urban wood waste studies.

Our survey estimate of 270,504 tons of annual used pallet generation, representing 46% of the UWW market, is relatively consistent with annual pallet production and the use of pallets by the automotive industry in the state.

The construction and demolition component streams are very difficult to quantify and assess. Regulatory uncertainty about the uses of demolition debris make this a highly problematic area.

Tree trimming residue is an area that bears further investigation since our survey estimates were preliminary and not as comprehensive as our survey of other UWW components. Railroad ties also represent a challenging area to assess since our research indicated that this stream may represent a significant quantity of UWW. Estimates may underreport generation as the quantity of currently stockpiled railroad ties is highly uncertain. Results of the Viking test burn will have extensive implications for both C/D and railroad tie waste streams.

The overall capacity utilization rate of 45% is skewed as a result of the very low capacity utilization rate reported in the demolition processing sector. Capacity utilization rates for other sectors are firmer estimates. These rates suggest that there is substantial room for growth in the UWW market.

Table 1. Annual Processing and Capacity Utilization Rates for all UWW Components (in tonnes)

UWW Type	Capacity	Quantity	Market Share	Utilization Rate	MegaJoules
Pallets	374,400	270,504	46.0%	72.0%	4.4×10^9
Wood Scraps	83,889	52,416	9.0%	62.0%	8.7×10^8
Construction (a)	232,713	81,549	14.0%	20.0%	1.4×10^9
Demolition	207,090	31,122	5.0%	15.0%	5.1×10^8
Tree Trim(b)	3,159 ---	2,633 46,951	8.0%	83% --	5.3×10^8
Land Clearing	9,360	6,318	1.0%	68.0%	6.6×10^7
Plywood/ Particleboard	15,795	9,945	2.0%	63.0%	1.6×10^8
RR Ties(c)	---	18,023 67,500	14.0%	---	1.4×10^9
Other	15,444	6,435	1.0%	42.0%	3.1×10^7
TOTAL(d)	941,850	593,395	100.0%	45.0%	9.3×10^9

(a) Capacity utilization rate is calculated for Detroit, Grand Rapids, and Lansing firms only; other area firms are excluded because capacity was not reported for all firms in other areas.
(b) Survey results of urban forestry and utility line clearance operations did not include capacity data.
(c) Rail line survey did not include capacity data.
(d) This overall capacity utilization rate is based on those firms reporting both capacity and UWW processing. This rate would most likely be greater if all firms reporting quantities of UWW processing included capacity as well.

The UWW market is one where a modest financial investment and individual initiative can result in a competitive and profitable enterprise. Based on an understanding of this niche market, independent entrepreneurs can become established and thrive in the UWW market. The key elements include knowledge of fuel specifications, securing a reliable supply commitment for end-user customers, technical capacity to process UWW for fuel, and delivering UWW to meet those specifications on time.

The conclusions presented here should be considered preliminary. We strongly urge that additional research be conducted to further illuminate the issues we have discussed. Policy makers should now have a clearer, more detailed picture of UWW as a key component of the solid waste stream.

CHARACTERIZATION OF WOOD ASH AND ITS REGULATIONS FOR LAND APPLICATIONS IN GREAT LAKES REGION

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Abstract

A serious barrier to the increased use of biomass fuels is the problem of ash disposal. The most cost effective way to dispose of wood ash is to apply/spread it on agricultural land. The ash buffers and acts as a source of fertilizer, avoiding the high cost of land filling. However, there are serious concerns by some state regulating agencies on the direct application of wood ash on soils. These concerns are based on the uncertainty of wood ash components and the environmental fate of heavy metals and organic compounds present in wood ash.

All the Great Lakes states studied in this report approved the land application of wood ash. However, each state had different analytical requirements for the wood ash characterization to obtain permit for land application. This report summarizes the state regulatory status of wood ash, agencies and persons to contact regarding the permitting procedures for land application. Also summarized are various types of analyses which are required for wood ash and the soil before the land application permit is approved.

As part of this study, wood ash from 45 industrial sites in the Great Lakes region were collected to characterize the wood ash generated using different type of fuels, wood species, sources, fuel mix, burners etc. A wide variation in the wood ash results were observed. No apparent correlation was found with the wood ash results generated between the different types of fuels, species, fuel mix, burners, large or small generators etc.

Problem Statement

A serious barrier to the adoption of biomass fuels in the Lakes States is the disposal and utilization of ash by-products. Users must have a means to dispose of ash that is cost effective, and does not degrade the environment or become a regulatory burden for the ash producer[1]. Until other beneficial uses are developed, the most cost effective way to dispose of wood ash is to apply it to soils. Using wood ash as a soil amendment has the advantage of acting as a soil fertilizer and buffer and avoids the high business and societal cost of landfill use.

The practice of land application has come under increasing regulatory scrutiny due to the uncertainty of composition and the ultimate environmental fate of the metals and organic compounds contained in the ash. While much work has been carried out to study coal ash, relatively few studies have focused on ash from woody materials. Studies conducted have been done indicate a high degree of metal concentration variability[2]. The variability of wood ash among various sources makes it difficult to develop beneficial uses.

An additional barrier to the adoption of biomass fuels in the Great Lakes region is the confusing regulatory environment surrounding the disposal of ash. There is no consistent procedure among the Great Lakes States for regulating the beneficial use of ash as a soil amendment. This has led to large regional, as well as state to state differences in whether ash is to be land filled or diverted to a beneficial use[3].

To address these issues, the Institute of Wood Research at Michigan Technological University has undertaken a research project to characterize wood ash generated in the Great Lake States to facilitate its beneficial use. This study focused on wood ash as opposed to a wider range of biomass fuels since the practice of generating energy from wood residues is already well established within the region's forest products industry.

For the purposes of this study, the Great Lakes States are considered to be Illinois, Indiana, Iowa, Michigan, Minnesota, Ohio and Wisconsin.

Project Overview

To study the issue of ash disposal from biomass boilers five primary tasks were undertaken: (1) State inventory information relating to wood burning boilers was gathered and summarized; (2) A literature review of publications relating to wood ash was carried out; (3) State regulations relating to the permitting of beneficial use of wood ash as a soil amendment were reviewed and summarized; (4) Wood ash samples were obtained from forty five industrial boilers throughout the Great Lakes States. The ash samples were then analyzed to document the range of properties, including elemental composition, pH, chlorides, conductivity, carbonates, sulfates, ammonia nitrogen, nitrate nitrogen, total Kjeldahl nitrogen, ash content and heavy metal concentrations; (5) In conjunction with the collection of wood ash samples, a three page questionnaire was sent to each participating company. The questionnaire was used to gather information on disposal practices of the surveyed companies.

The focus of this paper presents information relating to state regulations for permitting the land application of wood ash, the type of analysis required for land applications and the analytical results of wood ash samples collected from various sites during the study.

Summary of Wood Ash Regulatory Status

The burning of wood and wood residues is significant from a solid waste policy standpoint due to the concentration of elements or heavy metals and certain compounds. When wood is burned in an industrial burner, typically 3% - 7% of the incoming fuel weight remains as ash when combustion is complete. Volatile matter is driven off in the combustion process leaving ash (metals) and incompletely combusted carbon as the solid residues[4]. The amount of residue is affected by the type of burner used and operating parameters[5].

For a plant burning thousands of tons of woody material per year, the concentration of heavy metals and other naturally occurring compounds becomes a concern for ground water contamination when the ash is land applied. Other solid waste concerns result from the possibility that wood fuel may contain paint, wood preserving chemicals, old pallets stained with spilled chemicals, wood adhesives and other extraneous compounds. Some plants co-fire wood with old tires, coal or other organic wastes to make use of locally available fuels or to achieve better control of the combustion process. This can lead to regulatory differentiation between ash from "clean" wood and ash from wood contaminated or mixed with other fuels.

Federal Regulation of Wood Ash Disposal

At the federal level, wood ash disposal may be regulated by the Resource Conservation and Recovery Act (RCRA) of 1976 (42 USC 6901 *et seq.*) and the Hazardous and Solid Waste Amendments of 1984[6]. Certain exemptions from the act may apply, depending upon the nature of the facility, the fuel and the ash. Under RCRA, determinations of whether wood ash is to be treated as hazardous waste are based on the corrosiveness of the ash and whether it exceeds certain threshold concentrations for toxic contaminates as measured by a Toxic Characteristic Leaching Procedure (TCLP). The RCRA standard for corrosiveness of aqueous ash leachate is a pH of 2 or less or 12.5 or greater. Ash exceeding the RCRA thresholds must be handled and disposed of in a designated hazardous waste facility[7]. Most wood burning facilities that burn "clean" and "treated wood" have not experienced problems with ash being designated as hazardous according to a 1992 report issued by the New York State Energy Research and Development Authority[8]

If industrial wood ash does not trigger a hazardous waste designation under the RCRA criteria, an operator can elect to land apply ash if a market for the material can be found. In surveying industrial cooperators for this report, land application seems to be the preferred alternative among large producers of ash such as paper mills and wood-generating facilities. However, few small ash generators take advantage of this option. This would indicate that regulatory barriers combined with the initial cost of permitting land application, make land fill disposal of ash the preferred option for small producers.

State Regulations of Wood Ash Disposal for Land Application

All the Great Lakes States studied in this report approved the land application of wood ash. Table 1 summarizes the state regulatory status on wood ash, agencies and persons to contact regarding the permit procedures.

Table 1. State regulation of wood ash disposal

State	Regulatory Status	Wood Ash Beneficial Use	Permit Procedure	Contact Person
Iowa	Not defined. IAC 5/15/91 Ch 100	Yes, Iowa Fertilizer Law 1990.	Permit from IA Sec. Ag. Annually	Paul Lundy 515-281 8912 Lavoy Haage 515-281-4968
Indiana	Solid waste (329 IAC 2) [wood uncontaminated] Special waste (329 IAC 2-21) {wood contaminated)	Yes, Solid & Hazardous Waste Management Division (329 IAC 2-4)	Info. available from Solid Waste Permit Section	Dennis Lasiter 317-232-8732 LauraSteadham 317-232-8900
Illinois	Not regulated	No restrictions	Not applicable	Tony Pagel 217-244-6916
Michigan	Solid Waste	Yes, MDNR, under section 7(1)(g) Solid Waste Management Act,1978 PA 641	Info. available from Dept. of Natural Resources Waste Management Division	Duane Raskosky 517-335-4712
Minnesota	Solid Waste	Yes, Ground Water and Solid Waste Division	Info. available from MPCA	Jon Jordon 612-297-9707
Ohio	Solid Waste	Yes, Water Management Division	Info. available from Ohio EPA	Richard Fox 614-728-5370 Jenny Leshnock 614-644-2022
Wisconsin	Solid Waste (wood uncontaminated exempt)	Yes, Bureau of Solid Waste Management (ss 144.44 (7) (f) Stats.)	Info. available from Wisconsin DNR	Susan Fisher 608-267-9387

For land application permit each state has different analytical requirements for wood ash characterization. Tables 2 and 3 summarize the analyses required for wood ash and soil, respectively, before the land application permit is approved. It can be observed that a large variation on types of analysis required exists among the states, however very small changes were observed in the analytical requirements for soil. One of the reasons for uniformity in soil analysis among the states is that the states are applying the same regulations for wood ash as they require for land application of sludge.

It should be noted that states producing high volumes of wood ash are currently reviewing their regulations regarding wood ash disposal for land applications. During the survey, an interesting observation was made. Small generators (less than 10 tons per year) of wood ash preferred to use a landfill, rather than going through a permitting process for land application.

Table 2. Analysis required of wood ash to obtain permit for land application.

Type of Analysis	Iowa	Indiana	Illinois	Michigan	Minnesota	Ohio	Wisconsin
Dry Solids	✓	✓	×	✓	✓		✓
pH	✓	✓	×	×	✓		×
Total residue	✓	×	×	×	×		×
Volatile residue	✓	×	×	×	×		×
alkalinity	×	×	×	×	×		×
Sieve analysis	×	×	×	×	×		✓
Bulk dry density	×	×	×	×	×		✓
Total Kjeldahl Nitrogen	✓	✓	×	✓	×		×
Ammonium Nitrogen	✓	✓	×	✓	×		×
Nitrate Nitrogen	✓	✓	×	✓	×		×
Phosphorous	✓	✓	×	✓	×		✓
Potassium	✓	✓	×	✓	✓		✓
Boron	×	×	×	×	×		✓
Calcium	×	×	×	✓	✓		✓
Magnesium	×	×	×	✓	✓		×
Manganese	×	×	×	×	✓		×
Sodium	×	×	×	✓	✓		✓
Chloride	×	×	×	✓	✓		✓
Lead	✓	✓	×	✓	×		✓
Iron	×	×	×	×	×		×
Zinc	✓	✓	×	✓	✓		✓
Copper	✓	✓	×	✓	✓		✓
Nickel	✓	✓	×	✓	✓		✓
Cadmium	✓	✓	×	✓	×		✓
Chromium	✓	✓	×	✓	×		✓
Mercury	✓	✓	×	✓	✓		×
Molybdenum	✓	✓	×	✓	×		✓
Selenium	✓	✓	×	✓	×		✓

Type of Analysis	Iowa	Indiana	Illinois	Michigan	Minnesota	Ohio	Wisconsin
Arsenic	✓	✓	✕	✓	✓		✓
Aluminum	✕	✕	✕	✕	✓		✕
Silver	✕	✕	✕	✕	✕		✓
Sulfates	✕	✕	✕	✕	✓		✕
Electro Conductivity	✕	✕	✕	✕	✓		✕
Calcium carbonate equivalency	✕	✕	✕	✓	✓		✓
Neutralizing Index	✕	✕	✕	✕	✕		✓
Loss of ignition	✕	✕	✕	✕	✕		✓
Total phenols	✕ (a)	✕ (a)	✕ (a)	✕	✕ (a)		✓
Polynuclear Aromatic hydrocarbons	✕ (a)	✕ (a)	✕ (a)	✓	✓		✕ (a)
Polychlorinated biphenyls	✕ (a)	✓	✕ (a)	✕ (a)	✕ (a)		✕ (a)
Volatile Organic Hydrocarbons	✕ (a)	✕ (a)	✕ (a)	✓	✕ (a)		✕ (a)
Dioxins and Furans	✕ (a)	✕ (a)	✕ (a)	✓	✕ (a)		✕ (a)

Note: ✓ - required
✕ - not required
(a) This test may be required if using other than clean wood wastes.

Table 3. Analysis required of soil for permitting of land application of wood ash.

Type of analysis	Iowa	Indiana	Illinois	Michigan	Minnesota	Ohio	Wisconsin
pH	✓	✓	✓	✓	✓		✓
Bulk density	✓	✕	✕	✕	✕		✕
Texture	✓	✓	✓	✓	✓		✓
CEC	✓	✓	✓	✓	✓		✓
Current exchangeable cations	✓	✕	✕	✕	✕		✕
Lime index	✓	✓	✓	✓	✓		✓
Organic matter	✕	✓	✓	✓	✓		✓
Phosphorous	✓	✓	✓	✓	✓		✓
Nitrogen	✓	✓	✓	✓	✓		✓
Potassium	✓	✓	✓	✓	✓		✓
Boron	✓	✓	✓	✓	✓		✓
Manganese	✕	✓	✓	✓	✓		✓
Sulfur	✕	✓	✓	✓	✓		✓

Note: ✓ - required
✕ - not required

CHARACTERIZATION OF WOOD ASH

Procedure for collection of representative sources of ash

The ash was sampled from forty five different sites around the Great Lake States. The sites varied from small to large wood ash generators. The sampling protocol for the method was designed by EPRI for coal ash.[9] The individual samples were collected in Teflon lined containers at 24 hour intervals for four consecutive days. The containers held a 4 to 5 kilogram sample that was shipped from each site to the Institute of Wood Research. The sites which did not generate ash every day collected a homogenous sample. A composite sample was then made in the laboratory by mixing equal ratios of the four individual samples collected daily from the site.

Analytical protocol

The individual composite samples prepared were analyzed for the constituents listed in Tables 4 and 5. All the analysis were performed using either specified U.S.EPA methods or methods listed in "Methods of soil analysis Part I and II, NO. 9, American Society of Agronomy, Inc, Soil Science Society of America, Inc, 1986." The elemental composition results in Table 4 were determined using inductively coupled plasma atomic emission spectroscopy (ICP). During this study, no organic analysis was performed on wood ash samples.

Results

The results of the various analysis yielded variability among wood ash samples from all the sites. From Tables 4 and 5 illustrate the wide variation within each analysis. The wide range in the wood ash samples can be attributed to factors such as type of wood, species of wood, fuel mix, boiler type, large or small generators, etc. An attempt was made to determine the correlation between wood ash and some of the above mentioned factors. However, no apparent correlation was observed with the sample population in these studies.

Table 4. Variation in the elemental concentration of wood ash samples collected from forty five sites in Great Lakes States.

Analyte	Minimum	Median	Average	Maximum
Dry Solids (%)	40	99	92	100
pH	10	12.9	13	13
Alkalinity (%)	0.01	1.8	4	24
Electro Conductivity (mS/cm)	2	118	253	1298
Calcium (%)	1.6	1.8	1.7	36

Analyte	Minimum	Median	Average	Maximum
Potassium (%)	0.2	3.0	5.2	24
Sulfates (%)	0.01	0.6	4	26
Boron (mg/kg)	19	176	249	1,117
Chloride (mg/Kg)	5	897	5,503	123,750
Phosphorous (mg/Kg)	100	4,500	4,351	10,000
Total Kjeldahl Nitrogen (mg/Kg)	4	340	697	5,400
Ammonium Nitrogen (mg/Kg)	0.01	3.1	4	22
Nitrate Nitrogen (mg/Kg)	3	210	365	3,300
Sodium (mg/Kg)	256	1,910	4,410	44,533

Table 5. Variation in the metals concentration of wood ash samples collected from forty five sites in Great Lakes States

Analyte	Minimum	Median	Average	Maximum
Aluminum (mg/Kg)	1,346	6,088	8,454	51,646
Arsenic (mg/Kg)	19	102	113	1117
Cadmium (mg/kg)	8	8	14	83
Chromium (mg/Kg)	5	51	59	267
Copper (mg/Kg)	14	125	148	504
Iron (mg/Kg)	1,482	6,009	7,636	24,741
Lead (mg/Kg)	7	78	175	3,156
Magnesium (mg/Kg)	2,309	11,229	14,531	55,149
Manganese (mg/Kg)	407	2,505	3,271	16,1562
Mercury (mg/Kg)	0.003	0.072	0.077	0.500
Molybdenum (mg/Kg)	1	10	13	92
Nickel (mg/Kg)	4	24	40	233
Selenium (mg/Kg)	<20	<20	<20	<20
Sodium (mg/Kg)	256	1,910	4,410	44,533
Zinc (mg/Kg)	34	230	1,356	13,000

Conclusions

All the Great Lakes States studied in this report approved the land application of wood ash. However, each state had different wood ash analytical requirements for obtaining a land application permits.

The wood ash from forty five industrial wood burning sites around the Great Lakes States showed a wide variation in composition. No apparent correlation was found with the wood ash results generated between the different types of fuels, species, fuel mix, burners, large or small generators, etc.

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ORGANIC WASTE RECYCLING TO SHORT ROTATION WOOD CROPS

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Abstract

The current European use of inorganic fertilisers (N, P_2O_5 + K_2O) amounts to 18.8 M tonnes per year, 92% of which could be substituted for by animal wastes on the basis of nutrients supplied.

Substantial changes are taking place in the agricultural industry as land is taken out of food production and the area under non-food crops increases. Biomass energy crops may potentially form a substantial proportion of the alternative uses of agricultural land. Where these crops require fertiliser addition to optimise yield, organic wastes should be considered as low cost, low energy alternatives to inorganic fertilisers.

With correct planning and information provision, the expansion of short rotation wood crops may present the first opportunity to automatically regard organic wastes as the preferred nutrient source, and hence begin this process of inorganic fertiliser substitution.

Short rotation wood crops are also being developed as dedicated outlets and treatment systems for organic wastes and wastewaters. They offer an attractive option to farmers for whom the installation of waste treatment facilities can involve substantial investment for no direct economic return. Waste treatment and disposal on wood crops provides the farmer with an income from the wood generated. Hence the development of such systems may encourage better waste management.

A number of developmental systems have been installed. It is anticipated that at the current level of understanding, systems will predominantly be relatively small, a few tens of hectares, and extensive in terms of hydraulic and nutrient loading rates.

The ash produced by the combustion of fuelwood, has a fertiliser value and it is desirable that this be recycled to ensure that this renewable energy source is managed to minimise any potentially negative environmental impacts. The benefits and problems of ash recycling are briefly described.

Significant environmental and economic advantages can be derived from the integration of waste management and fuelwood production. The active development of this integration will help promote the wider adoption of fuel wood production, especially of the fuel can be utilised directly by the waste producer.

Introduction

It is estimated that at least 1 billion wet tonnes of organic wastes are produced annually in Europe, of which about 200 million is sewage sludge (Hall and Dalimier 1994). The current European use of inorganic fertilisers (N, P_2O_5 + K_2O) amounts to 18.8 M tonnes per year, 92% of which could be substituted for by animal wastes on the basis of nutrients supplied. At its current level of use in agriculture across the European Union, sewage sludge could substitute for 1% of the applied inorganic fertilisers (Riddell-Black and Hall 1995). There is considerable degradation of drinking water supplies and aquatic ecosystems associated with the widespread, heavy use of nitrogen fertilisers. Legislation at both national and European level, continues to be introduced in an attempt to control nutrient dispersal (CEC 1991a, 1991b, 1986). Greater substitution of inorganic fertilisers with organic wastes could bring substantial environmental benefits as well as financial and energy savings.

The agricultural industry across Europe is undergoing substantial changes as pressure to reduce food surpluses is forcing farmers to diversify into new non-food crops. Crops for fuel, fibre and chemicals are of particular interest as all these materials are in net deficit within the Union. In the UK, and other areas of Northern Europe such as Sweden, Denmark and The Netherlands, short rotation wood crops of willow and poplar are probably the closest of the fuel crops to commercial production. The recycling of organic wastes and wastewaters to this crop has been receiving a considerable amount of attention, and number of schemes for the integration of fuel production and waste management are either in place or planned.

Organic wastes may be used for energy production during the processes necessary for their treatment and disposal such as anaerobic digestion and incineration. On a dry weight basis , organic wastes and biomass energy crops have similar calorific values. Sludge incineration technology is now such that the process is autothermic. On-farm waste digestion is increasingly becoming an economic reality as process technology improves. Hence, it could be suggested there is no benefit to be derived from using wastes as fertilisers for fuel crops, when they could be used directly as fuels. Yet there are several arguments in favour of waste use for SRF production. In not all circumstance will either incineration or digestion be an appropriate technology. These systems will tend to take over when the scale of operation requires too great a land area or investment in infrastructure for application to SRF to be a realistic option. Without the installation of primary and secondary treatment facilities such as exist at sewage treatment works, neither is appropriate where the waste is characterised by high volume and low solids content. Hence, organic waste use on SRF is a generally low technology system which can be adapted to a wide range of materials and situations. The use of organic wastes as fertilisers for short rotation wood crops may promote better waste management if the system can be operated for less cost than the alternatives and if an income can be derived from the 'treatment system' ie the fuel crop.

Overall, the use of wastes to promote growth of energy crops such as short rotation forestry (SRF) would appear to be a more sustainable use of these materials, particularly as it is debatable whether these materials can genuinely be regarded as renewable fuels. A life cycle assessment study is currently underway at WRc to investigate the environmental merits, including energy return, of directly incinerating sewage sludge, as compared with its indirect incineration by its application to a SRF crop grown for fuel.

This paper explores the opportunities for the integration of organic waste management with fuel wood production and describes some examples which are already in place. Brief consideration is given to design criteria such as nutrient and hydraulic loading rates. Finally, the use of the waste generated by wood fuel crops, that is ash, in the further production of fuel is considered.

There is still considerable conjecture as to whether short rotation wood crops actually require to be fertilised to maintain productivity. For every study which has demonstrated a significant crop response to the addition of nutrients, there is one which demonstrates the opposite. There is insufficient space to discuss the nutrition of SRF at this point and readers wishing to investigate this aspect further are directed to Ericsson *et al* (1992) and Heilman (1992). It is sufficient to say that the high yields and frequency of harvesting suggest that soils will become depleted within the 20-30 year life of a SRF plantation. Regular nutrient addition will offset this export and limit any tendency towards yield depression.

Forestry crops rely almost totally on internal nutrient cycling mechanism for growth once canopy closure is achieved (Millar 1989). The time taken for this to occur is dependant on species and site conditions. Canopy closure is achieved artificially quickly in SRF crops, frequently within the planting year, due to the close planting densities employed, typically 10 000 to 20 000 trees per hectare. However, nutrient cycling, may not develop the same extent in SRF systems due to the frequent removal of nutrients in harvested stems. This is more particularly the case for willow in which the major portion of nutrients translocated for winter storage are located in stems (Ericsson and von Fircks 1985, Sauter 1981). The major storage pool of translocated foliar N in T x D hybrid poplar has been associated with large structural roots (Pregitzer *et al* 1990).

The quantity of level of nutrient exported from a site is a function of yield and stem nutrient concentration. Stem wood N concentrations are typically in the region of 3-4 kg t^{-1} dry matter (Ericsson *et al* 1992). However, willow stem concentrations have been measured at two and a half times that level at a site where soil nutrient status was very high (Riddell-Black, unpublished). It would appear therefore that nutrient export can be increased beyond that which could be expected from analysis of tissue sampled from crops grown under normal agricultural plant conditions. It is partly this apparent ability to take up luxury concentrations of nutrients that has stimulated consideration of SRF as a waste management mechanism.

Waste management systems

The use of waste materials in wood crop production can be operated at a range of intensities, depending on whether the primary objective is wood production or waste management. However, the same control criteria need to be applied in both situations, that is, the capacity of the crop to take up the applied nutrients and transpire the applied water should not be exceeded. Where application rates are to be greater than the plant assimilative capacity, the role of the soil becomes much more important to the successful operation of a system. This constitutes a more intensive use of the plant-soil system and is more akin to an engineered treatment system. Greater control and monitoring mechanisms will be required to avoid system failure. At our current level of knowledge, organic waste use and disposal on SRF will be operated extensively. Plantations can be established as a dedicated outlet for a specific waste or wastewater. However, application rates will be no more intensive than if the waste was applied to a plantation in substitution for an inorganic fertiliser.

Animal slurries pose a much greater risk to the environment than does sewage sludge purely by virtue of the much greater volumes of these materials that are produced (Table 1). Despite this, the treatment and disposal of sewage sludge is much more tightly controlled. Significant environmental benefit could be derived of SRF can be developed as a cost effective waste management system for slurries, dairy washings and silage effluent all of which are frequent sources of pollution events.

Table 1 Annual Volume of Excreta Production by Animal Type (From Cooke 1986)

	Volume excreta production per year (m^3)	Moisture content (%)
Dairy cow	15	87
Bullock	10	88
Pig (dry feed)	1.46	90
Pig (liquid feed)	2.5	94
Pig (whey feed)	5.1	98
Human (following secondary sewage treatment)	1	3

The integration of waste management and fuel wood production would appear to be best suited to small self contained systems such at for individual farms, small rural sewage treatment works, or individual factory units such as a vegetable processor or paper manufacturer. In these situations it is possible to operate with virtually no requirement to transport the waste materials, which may be piped directly onto a SRF plantation located on the farm, or adjacent to the treatment works or factory. There are a number of examples where this is already occurring in Sweden, Denmark and New Zealand.

In Sweden, interest is more closely focused on the irrigation of wastewaters and effluents to energy forests. Stringent controls on nutrient discharges to water courses from sewage treatment facilities means that high costs of chemical nutrient removal are incurred. The nutrients present in the effluent before chemical treatment closely match the ratio in which they are required by SRF (Perttu 1992). Hence, SRF offers a cost effective alternative to traditional treatment systems. These schemes are fully described by Aronsson and Perttu (1994).

A number of small experimental schemes have been installed in Denmark. One such system was installed to treat the peak flow of sewage from a zoo in the summer when visitor numbers are high. hoses The sewage effluent is irrigated by leaking hoses, following primary settlement, to willow planted for the purpose. In this case the requirement for a treatment system exactly coincides with the maximum assimilative capacity of the trees, that is when they are growing (Nielsen 1992, pers. comm.).

At Oringi, North Island, New Zealand, meat processing effluent is irrigated at to an intensive crop of Eucalyptus at 3 t N ha^{-1} per annum. It would be reasonable to expect that this is beyond the capacity of the trees alone to assimilate and that soil process are an important component of this system. Eucalyptus are also utilised to treat and dispose of effluent produced by wool processing facilities (Sims 1993, pers. comm.).

In the UK, a significant proportion of the sewage treatment works operated by the water utility companies serve populations of less than 1500 persons. In the Anglian Water region, 700 of the 1100 works operated by the company are of this size. If a daily per capita solids production with primary and secondary treatment, of 0.082 kg is assumed, the entire annual sludge production from a works serving 1500 people would require 12 hectares of SRF if applied at 120 m^3 ha^{-1} per annum (approximately 250 kg total N ha^{-1}). Similar rather crude calculations can be made for the area SRF required for disposal of animal slurries. However, figures calculated from mean values can be regarded only as being indicative of the volume of livestock waste which can be applied to each hectare of SRF, due to the highly variable nature of these materials.

Application rates must take account of local conditions and general calculations such as those discussed in the preceding paragraphs should be modified accordingly. The maximum quantity which can be surface applied at one time to a flat site, without risking surface run off is 200m^3 ha^{-1}. This will need to be reduced on sloping sites and in the vicinity of water courses. Buffer strips at the margins of a plantation should be left unapplied to guard against nutrient loss to neighbouring land. Calculations of hydraulic loading rates and nutrient assimilative capacities will not necessarily suggest the same design area, in which case the larger area should be selected.

The scale and extent of treatment of sewage sludge generally produces a more consistent and predictable organic fertiliser for agricultural use compared with the wastes of farm animals, which are potentially highly variable in composition and nature. Hence, it is generally easier to be precise about the nutrient content of a sludge produced at a treatment works. Consequently, SRF plantations established to recycle a fixed quantity of sewage sludge need have less latitude in its design area than a plantation to which animal slurries, silage effluent or dairy washings are to be applied.

A number of large schemes are planned, but the capital and infra-structural requirements of these are such that it is hard to appreciate in what manner they are preferable to more traditional engineered approaches to waste management. In Sweden, an assessment has been made of the land requirement to treat all the wastewater arising from Landskrona, a town with a population of 40 000. Nitrate removal by chemical means presently costs £5 - 10 kg^{-1} N. An estimate 1200 ha of SRF, applied at an annual rate of 600 mm ha^{-1}, is required to absorb the total waste production and meet discharge consents for N and P. The availability of land is such that the effluent must be piped 25 km to the planned location of the plantation. Despite this, the cost of transport has been estimated as being only 4% of the total system cost and an annual saving of £100 000 is anticipated (Perttu 1993, pers. comm.).

The largest scheme currently planned in the UK involves the application of sewage sludge. An 8 MWe wood gasifier is planned in Yorkshire. This is to be supplied by fuel from 2500 ha of SRF which will be planted for the purpose and receive sewage sludge as a fertiliser. With both these schemes a primary consideration will be the storage requirement for the waste materials when the crop is not actively growing and hence not taking up nutrients or transpiring applied water. The cost and benefits, and payback on investment on projects of this scale have to be closely examined to establish whether they truely offer a better option. Equally importantly, the environmental impact of operations involving several 1000 ha need to be rigorously assessed.

The combustion of clean wood produces very low amounts of ash, typically 0.5 to 2% compared with around 10% for coal. However, in locations where wood contributes substantially to power production, such as in Sweden and Austria, the quantity of ash requiring disposal can be significant. Between 1.5 and 2 million tonnes of wood ash is produced annually in the United States, predominantly by power stations, the majority of which is landfilled (Campbell 1990). Concern to ensure that the environmental impact of biomass energy crops is minimised has stimulated interest in returning the ash to the site of energy crop production as a P and K fertiliser and liming agent. This use of wood ash can also improve the economics of energy crops by eliminating both the need to purchase fertilisers and the cost of ash disposal.

Wood ash has a K content of between 2 and 6% by weight, a P content of 0.7 - 2.2 %, as well as containing 21-33% Ca and 2-3.5% Mg (Eriksson 1993, Erich 1991). Recommendations for the addition of K to short rotation forestry of willow and poplar range between 30 and 80 kg ha^{-1} applied annually or once every three years (Sennerby-Forsse 1986, Shoulders and Wittwer 1979). If an ash K content of 4% is assumed, 80 kg K will be supplied by 2000 kg of ash.

It has been suggested that the combination of wood ash with organic wastes can improve the nutrient balance of both materials such that they better match the nutrient requirement of SRF (Perttu 1994) Table 2). Combining the two nutrient sources prior to application would effectively half the cost of applying them separately. However, the admixture of a high pH material with an organic waste containing a high proportion of nitrogen in ammoniacal form, such as liquid digested sewage sludge or pig slurry, could result in the loss of the majority of the NH_4-N to the atmosphere through volatilisation. It may be possible to encorporate wood ash to raw sewage sludge, as a substitute for the mineral lime used, on occasion, during processing to control odour and render the sludge more amenable to dewatering. This may reduce sludge processing costs. However, the ash cannot be directly recycled to the energy crop production site from which it originated in this form, as dewatered sludge can only be an effective fertiliser for SRF if encorporated to the soil prior to planting.

Table 2 Quantity of Nutrients Delivered by 1800 kg of Sewage Sludge and 1200 kg Wood Ash Compared with the Optimum Required to Produce 10 odt ha^{-1} Willow Stem Wood (from Perttu 1993).

Nutrient	Willow requirement (kg)	Content in sludge (kg)	Content in wood ash (kg)	Content in mixture (kg)
Nitrogen	60	60	0	60
Phosphorus	8	44	20	64
Potassium	43	5	38	43
Calcium	4	122	244	366
Magnesium	5	5	22	27

There are two principal drawbacks to the recycling of wood ash: its high pH and the presence of heavy metals. The pH of wood ash is in the range 11 -12 (Eriksson and Borjesson 1991). This makes it a useful lime substitute. In particular, the long term buffering capacity of the soil may be improved in coniferous forests suffering the effects of soil acidification by acid rain. A single 5 t ha^{-1} application of conifer bark ash to drained, cultivated peatland was found to increased soil pH from 5.1 to 6.5-7 (Lumme and Laiho 1988). However, the direct application of ash powder potentially could have severe localised effects on soil chemistry and biology and could cause leaf scorching on contact with the crop. Pelletisation of ash has been found to be effective in controlling the rate of the liming effect of ash (Rosen *et al* 1993) so this concern may be overcome.

Trees and in particular, conifers capture dust particles from the atmosphere in their canopy. This dust contains heavy metals from both anthropogenic and geological sources, such as volcanic eruptions. This capture can lead to relatively high concentrations of heavy metals being concentrated in the wood ash. Already, in Sweden there are controls on the return of wood ash to the source forest, on the basis of their heavy metal.

Interest in the use of waste materials, and in particular sewage sludge, as fertilisers for SRF has prompted several studies of the heavy metal take up by willow and poplar (Dickinson *et al* 1994, Landsberg and Greger 1994, Riddell-Black 1994). There are preliminary indications that Cd and to a lesser extent Zn can be taken up such that concentrations in the stem tissue are higher than soil concentrations(Table 3). This has been found to occur even where soil concentrations are at background levels (Riddell-Black 1995, Nielsen 1994).

Table 3 Cadmium Concentrations in Willow Stems Grown at Sites with Different Soil Concentrations. (From Nielsen 1994(1), Riddell-Black 1995(2))

Willow variety	Soil concentration ($mg\ kg^{-1}$)	Soil pH	Stem concentration ($mg\ kg^{-1}$)
Salix viminalis 78-112 (1))	0.16	6.00	1.07
Salix dasyclados (2)	0.54	6.28	3.06
Salix dasyclados (2)	5.35	6.10	6.20

Heavy metals taken up into the wood by energy forestry species will be concentrated in the ash on combustion, and hence wood ash use as a fertiliser could potentially redistribute the heavy metal to agricultural land. The application of sewage sludge in the UK is controlled by the nutrient addition rates and by the accumulation of metals in the receiving soil. An application of 100 $m^3\ ha^{-1}$ of sewage sludge at 3% dry matter and Cd concentration of 6 $mg\ kg^{-1}$ dry matter, would deliver 18g of Cd to one hectare of soil. The application of wood ash at 2000 $kg\ ha^{-1}$ to supply 80 $kg\ ha^{-1}$ which has originated from short rotation willow stems with a pre-combustion concentration of 2 $mg\ kg^{-1}$ Cd, K would deliver in the region of 400g of Cd ha^{-1}, assuming an ash content of 1%. Although it may be argued that the heavy metals in the wood ash originated from the agricultural land, the application of such quantities of metals is unacceptable. Hence, it may be necessary to screen SRF varieties developed by current breeding programmes, to isolate those which have a low capacity to take up heavy metals in the harvested portion of the crop, ie in the wood.

Combustion chamber design and ash separation also offer additional safety guards against the return of heavy metals to the soil in recycled ash. Metal concentrations are substantially lower in bottom and cyclone ash, than in the ash condensed from flue gases. (Obernberger 1995). This filter fly ash fraction represents only 5-10% of the total ash produced yet it contains 30 to 50% by weight of the Cd and 25-46% of the zinc present in the wood (Obernberger 1995). In combusting wood containing 0.89 $mg\ kg^{-1}$ Cd, Nielsen (1994) measured fly ash concentrations of 53 $mg\ kg^{-1}$ and bottom ash concentrations of 2.1 $mg\ kg^{-1}$ the latter constituting 85% of the total ash derived. Combustion chamber design can influence the proportion of fly and bottom ash derived and chamber design potentially can be manipulated to a limited degree to maximise heavy metal separation from the majority of the ash.

Conclusions

The recycling of organic wastes and wastewater effluents to short rotation wood crops has many attractions. However, it also has a number of associated hazards if not managed correctly. The apparent environmental and economic gains which can be derived from integrating waste management with renewable fuel production are such that there is considerable pressure to implement schemes before the system dynamics are fully understood. The resultant bad publicity associated with massive system failure of one project which has progressed too rapidly potentially could severely impact on the wider and longer term development of such schemes, whether managed intensively or extensively.

The same control criteria should be applied regardless of whether a material is regarded as being treated, disposed of, or recycled. The plant-soil system has a finite nutrient assimilation capacity. This potentially can be manipulated to a degree, but the opportunities are currently restricted given the limited level of understanding of the various processes at work, their patterns of integration and long term stability. The nutrient and hydraulic loading rates with which wastes are applied must be within capacity of the system to assimilate, otherwise there will be no environmental benefit to the development of integrated waste management and fuel wood production. Indirect economic disbenefits of poor system operation will also be felt in the form of higher drinking waster treatment costs. At the present level of understanding, this is likely to limit the development of waste use in wood crop production to extensive or intermediate systems, in terms of loading, infrastructure and management.

There is a need for full-scale demonstration of the principles in a wide range of situations and backed by intensive research support. This will provide information for the development of practical guidelines on the design and management of integrated wood production and waste management systems, while also providing clear information on the limitations and potential environmental impacts of integration of these technologies.

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PERSPECTIVES FOR ENERGY PROCESSING OF WASTE BIOMASS IN BULGARIA

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Abstract

Biomass is a renewable energy resource and is especially important now because fossil energy sources are almost exhausted. Bulgaria is not rich in fossil fuels. Its total industrial reserves of coal are equal to 825 Mt OE. The total primary energy supply in Bulgaria in 1992 was 402 PJ, or 9,6 Mt OE. A significant part of primary energy needs is imported, so the national economy is dependent on world fuel prices. Waste biomass-to-energy systems could be a good alternative. Approximately 60% of Bulgaria is arable land and about 30% is forest. The calculations of the energy equivalent of waste biomass alone in 1992 show that the total energy that could have been obtained by biomass processing is about 90.5 PJ or 2 Mt OE. This is about 22% of the total energy consumption in Bulgaria in 1992.

INTRODUCTION

The fossil fuel resources of our planet are limited. The fast increase of world population leads to rapid exhaustion of available energy resources and at the same time to an accumulation of the environmental pollution. That is because many countries search for alternative energy sources, which could allow in the same time to limit the pollution of soil, water and air. Along with the technical transformation of solar and wind energy, the obtaining of cheep bioenergy is one of the possible ways to solve the problem. Biofuel can be obtained by different ways: direct combustion of biomass, hydrolysis, pyrolysis, methanisation (anaerobic decomposition) etc.

Very often agricultural and forestry residues are used for processing of biomass to energy. Recently house hold and municipal wastes are also used for energy production.

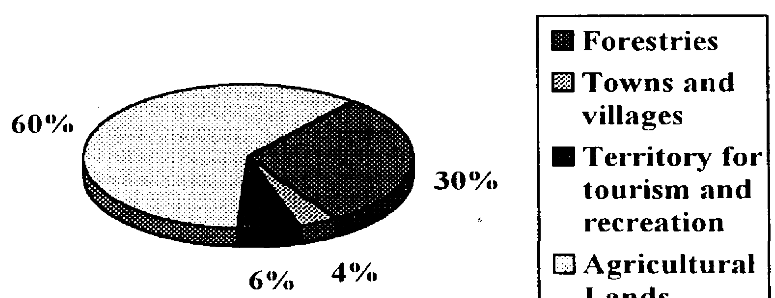
BIOMASS RESOURCES IN BULGARIA

Bulgaria is a land of wide variety of natural components, changing very expressively from north to south. The large flat countries (the Danube Plain) alternate with massive mountain chains (the Balkan Mountain). Lower mountains and hills diversify the appearance of plains (the Thracian region with the Strandzha mountain, the Rila-Rhodopes' region).

Approximately 60% of the territory of Bulgaria (flat countries and hills) is occupied by arable lands and agricultural breeding. The forestries take the second place with about 30% of the territory. They occupy the medium - and high - mountain regions. About 6% of the territory represent places intended for tourism and recreation.

Towns and villages take 3-4% of the territory (See the diagram on Fig.1).

Fig. 1



Energy Situation in Bulgaria

In world's plan Bulgaria is not rich of fossil fuels. There are oil fields in Pleven's district and on the cape Shabla, Varna's district. Coal fields are situated near Lom, Sofia, Elhovo, along the river Maritza, near Burgas, Sliven, Bobovdol etc.
A natural gas has been found near the village Devetaki, Lovech's region and around the outfall of the river Kamchia .
The industrial reserves of coal are given in Table 1.

Table 1
Industrial Reserves of Coal in Bulgaria

Kind	Amount, million tons	%	Mt. OE
Light Coal	4500	92.6	703
Brown Coal	300	6.7	106
Hard Coal	22	0.5	12
Antracite (stone) Coal	9	0.2	4
Total			825

Total industrial reserves of coal in Bulgaria is equal to, 825 Mt. OE.
Data shown in Table 1. monitor the provision of Bulgaria with domestic primary energy sources. A significant part of primary energy sources is imported, so the national economy depends on the fuel prices on world market.
According to the Report of European Bank for Reconstruction and Development ("Energy in Danubian Countries", September 1992) two times more energy is consumed per unit national domestic product in Bulgaria than in the EEC countries.
Production of electricity and thermal energy by nuclear and hydroelectric power plants can be used for estimation of energy intensity. It is shown in Table 2.

Table 2
Production of Electricity & Thermal Energy

Year	1990	1991	1992
Electricity, million kWh	42 141	38 917	35 587
Thermoelectric Power Plants	25 592	23 292	21 972
Nuclear Power Plant	14 665	13 184	11 552
Hydro Power Plant	1 878	2 441	2 063
Thermal Energy, kcal	44 709	37 000	31 471

In the period of changes the energy production in Bulgaria decreased, as data in Table 2 show

The expenses for electricity produced by different plants in 1992 can be seen in Table 3.

Table 3
Expenses for Electricity Production (with amortisation)

Kind of plant	Expenses, BGL / kWh	Relative part of fuel component to the total expenses, %
Thermo-nucleic Power Plant	0.58	68
Hydroelectric Power Plant	0.21	-
Nuclear-electric Power Plant	0.28	42

The rate at 1992 was 1USD = 20BGL

Agriculture

Agriculture is traditional part of Bulgarian economics.
Last five years in connection with the changes in Bulgarian economics (the pass to market economics) the part of agriculture grew up in Bulgaria. Private agricultural farms appeared. Some data about agriculture in Bulgaria are shown further down. Table 4 shows the area soon by different plants, Table 5 - the production of main agricultural products.

Table 4
Area Sown

(thousand hectares)

Indicator	1991	1992
Cereals in total	2337	2291
of which		
Cereals bread crops	1225	1129
Cereals fodder crops	1055	1117
Oil crops in total	287	490
of which		
Sunflower	270	476
Area sown in total	3764	3850

Table 5
Production of Main Agricultural Products

Indicator	thousand tons		tons per hectare	
	1990	1992	1990	1992
Wheat	5 292	3 443	4.55	3.11
Rye	49	35	1.99	1.60
Barley	1 387	1 195	3.85	3.05
Maize	1 221	1 742	2.87	2.81
Sunflower	389	595	1.39	1.25
Sugar beets	584	304	16.67	17.78
Table grapes	68	81	4.91	5.02
Wine grapes	563	616	4.42	4.94

The wastes from agriculture can be estimated on the basis of data about agricultural residues from different crops (Yankov B., 1994).

Table 6

Residues from Different Crops

(tons per hectares)

Indicator	Utilised residues	Waste
Wheat	1.5	0.55
Rye	2.0	0.55
Barley	1.5	0.55
Oats	1.5	0.55
Rape		3 - 4
Maize		3 - 4
Soybeans		0.5 - 0.6

The land occupied by vineyards in Bulgaria at the end of 1993 was 126 thousand ha (Pandeliev S., 1994). The agricultural residues from vineyards are 15.12 tons/ha per year.

These data allow to estimate approximately the total amount of agricultural residues per year in Bulgaria, which are not utilised. The total amount for crops, both cereals and oil crops may be estimated at 2975 thousand tons per year. The residues from vineyards in Bulgaria per year can be evaluated at 1905 thousand tons. Therefore the total amount of initialised agricultural residues per year is 4880 thousand tons. Let us accept that the calorific value of these residues is: wood-chips 18,5÷20,7 MJ/kg straw 15-16 MJ/kg, municipal waste - 14-15 MJ/kg. The mentioned amounts can be evaluated - first at 44,6 PJ and second at 36,2 PJ or total 80,8 PJ, equal to 1,9 Mt. OE. This value represents 25% of the total primary energy supply in Bulgaria for the same year.

Livestock is other important part of agriculture. The industrial livestock complex is an artificial ecological system. In the case of intensive livestock the amount of wastes and

specially of liquid manure is quite large. Liquid manure contains different micro-organisms, which are dangerous for people as well as for animals. On the other hand the manure has high energy potential and it is a renewable energy source.
Next tables 7, 8 give some important data on livestock in Bulgaria.

Table 7
Livestock

Indicator (Total)	1990	1991	1992
Cattle	1 575 107	1 456 900	1 310 454
Buffaloes	23 046	25 517	25 164
Pigs	4 331 625	4 186 575	3 141 402
Sheep	8 130 305	7 938 056	6 703 372
Goats	432 927	498 087	552 736
Horses	118 902	115 425	114 267
Poultry	36 338 040	27 998 430	21 707 200

Last five years increased the number of private farms, as the next table shows.

Table 8
Livestock in Private Sector

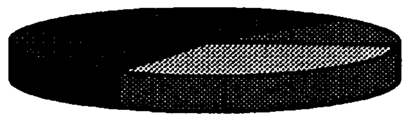
Indicator	1990	1991	1992	1993
Cattle	282 348	389 656	418 282	488 402
Buffaloes	14 059	17 257	17 999	17 540
Pigs	865 202	1 031 242	820 030	837 875
Sheep	2 549 364	3 177 802	3 260 660	3 582 148
Goats	428 965	495 133	550 516	610 233
Horses	94 437	94 089	97 368	103 197
Poultry	13 714 515	12 481 322	10 681 953	12 001 332

The total amount of liquid manure produced in Bulgaria in 1992 can be estimated at 11,2 million tons. It pollutes the waters and could be used for production of different useful products.

Wood waste utilisation in Bulgaria

The diagram shown on Fig.2. expresses the relative part of wooded forest area to the total area, as in 1992.
Data on afforestation are based on inventory of forests. Substitution of trees is made by cutting of unacceptable tree species out of condition and afforestation of new ones of good quality in genetic and technical sense.

Fig. 2



According to the Statistical Year Book, 1992 in Bulgaria there are 228 small, middle and big plants in Wood & Furniture Industry (WFI). There are also 19 plants in Pulp & Paper Industry (PPI). The final consumption of energy in these branches of National Economy for 1992 was 5584 TJ in WFI and 6110 TJ in PPT.
In Table 9 the wood wastes occurrence in 1992 and 1993 is given.

Table 9
Wood Wastes Occurrence

(thousand tons)

Indicator	1992	1993
Tree barks from Wood & Timber Industry	145.8	168.3
Shavings, sawdust, chips	11.1	8.3
Wastes from particle boards	0.15	1.1
Lime middling slime from pulp industry	43.7	44.4
Other wood wastes	34.6	36.8
Total	235.2	258.9

Tables 10 and 11 monitor the wastes from WFI and PPI, respectively.

Table 10
Timber Wastes

Indicator	thousand tons	%
Stock in the beginning of year 1992	280.9	
Arising	80.8	
Received from Other Plants	0.5	
Total in 1992	362.2	100
of which:		
Utilized	7.2	2
Delivered to Other Plants	42.1	12
Tipped by the end of the year	235.2	65
Irreparably losses	75.5	21

Table 11
Paper and Cardboard's Wastes

Indicator	thousand tons	%
Stock in the beginning of year 1992	47.1	
Arising	11.3	
Total in 1992	58.4	100
of which:		
Utilized	1.2	2
Delivered to Other Plants	45.3	78.6
Tipped by the end of the year	9.6	16.4
Irreparably lost	1.6	3

Wastes do not include the own production wastes in the same unit.
Utilised wastes are those excluding the own production wastes, put in production as material resources.
Formation of Household Wastes is given in Table12.

Table 12
Arising Household Wastes

Indicator	1985	1990	1991	1992
Total, thousand tons	6773	8022	8503	8067
Per capita, kg	756	892	947	945
Area of dung-hills, ha	640	700	710	760

An estimation of the quantities utilisable for energy-in-biomass processing can be made according to data in Table13.

Table 13
Utilisable Biomass Waste

Indicator	1991	1992
Fire Wood, thous. cub. m	1660	2072
Fire Wod, thous. tons	11.6	14.5
Forestry Residues, thous. tons	150.2	235.2
Agricultural Residues, thous. tons	5010	4880
Household Wastes, thous. tons	8503	8064

Table 14
Energy Equivalent of Waste Biomass

Indicator	GigaJoules	Tons Oil Equivalent
Fire Wood	290 080	6 961
Forestry Residues	4 114 250	99 000
Wood Wastes	5 178 000	124 000
Agricultural Residues	80 800 000	1 900 000
Household Wastes	193 000	4 632
Total	90 575 000	2 134 593

Total energy which could be obtained by biomass processing in Bulgaria can be evaluated to 90,5 PJ or 2 Mt. OE. This makes about 22 % of the total primary energy supply in Bulgaria for 1992.

CONCLUSIONS

Information collected under the conditions of the contract shows that there is a durable interest for biomass- to- energy processing in Bulgaria. A long-term plan for development of technology and search of constructional solutions for this matter has existed. Unfortunately at the present this plan is not realisable.

There is a trend to build plants for processing of solid municipal wastes. Conversations about realisation of such projects are conducted in Sofia (with the Italian company "Riorsi"), in Plovdiv (with the French company ABCM), in Shumen (with Danish company "Scancar"). As in the case of realisation of biogas installations, in the case of building of plants processing solid municipal wastes the biggest problem is the lack of investment means. It is well known that biomass- to- energy processing needs considerable capital investment.

A significant interest exists for renewable energy sources in the scientific areas as well as in the municipalities.

This interest is based mainly on the ecological priorities, given by the biomass- to- energy processing.

It is of great significance also the possibility by this way to create an alternative of the National Electric Company - monopoly organisation which presently dictates the prices of electricity and therefore of heating.

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RESEARCH TO DEVELOP IMPROVED PRODUCTION METHODS FOR WOODY AND HERBACEOUS BIOMASS CROPS

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Abstract

The Department of Energy's (DOE's) Biofuels Feedstock Development Program (BFDP) has led the nation in developing short-rotation woody crops (SRWC) and herbaceous energy crops (HEC) as feedstocks for renewable energy. Over the past 15 years, the BFDP has examined the performance of 154 woody species and 35 herbaceous species in field trials across the U.S. It has managed research projects involving more than 100 federal, university, and private research institutions. One result of this effort to date has been the prescription of silvicultural systems for hybrid poplars and hybrid willows and agricultural systems for switchgrass. Selected clones of woody species are producing dry weight yields in research plots on agricultural land that are 3 to 7 times greater than those obtained from mixed species stands on forest land, and at least 2 times the yields of southern plantation pines. Selected switchgrass varieties are producing dry weight yields 2 to 7 times greater than average forage grass yields on similar sites. Crop development research is continuing efforts to translate this potential, in a sustainable manner, to larger, more geographically diverse acreage. Research on environmental aspects of biomass crop production are aimed at developing sustainable systems that will contribute to the biodiversity of agricultural landscapes. Systems integration aims to understand all factors affecting bringing the crop to market. Factors affecting price and potential supplies of biomass crops are being evaluated at regional and national scales. Scale-up studies, feasibility analysis and demonstrations are establishing actual costs and facilitating the commercialization of integrated biomass systems. Information management and dissemination activities are facilitating the communication of results among a community of researchers, policymakers, and potential users and producers of energy crops.

Introduction

The U.S. Department of Energy (DOE) has supported a national research program on biomass production for energy since 1978. Broadly stated, the mission of the DOE Biofuels Feedstock Development Program (BFDP) is to provide leadership in developing and demonstrating environmentally acceptable and commercially viable biomass supply systems. The mission is being pursued in a way that (1) integrates and promotes multiple objectives for agriculture, energy and the environment; (2) seeks and fosters the best research, development, and demonstration in the private, academic and government sectors; and (3) ensures information on biomass supply systems is accurate, understandable, and accessible. This mission has been undertaken to insure (1) new, profitable and environmentally acceptable cropping options for biomass producers; (2) secure, affordable and sustainable supplies for biomass end-users; and (3) that up to 15% of the U.S. primary energy demand can be met from biomass. The BFDP is managed by the Environmental Sciences Division of Oak Ridge National Laboratory (ORNL), Oak Ridge, Tennessee.

Related to the BFDP mission are the issues of domestic energy security, rural job creation, CO_2 mitigation, and global warming. Renewable energy from biomass creates the potential to favorably influence each of these issues. The intent of the BFDP is to develop technologies that can be a major contributor to achieving or exceeding EPAct requirements (Section 502) of producing sufficient domestic replacement fuels to substitute, on an energy equivalent basis, 10% by 2000 and 30% by 2010 of the project consumption of motor fuel by light duty vehicles in the U.S. (DOE, 1994). This would require a feedstock supply of between 190 and 527 million tons per year of raw lignocellulosic biomass, depending on the efficiency of converting the feedstock to transportation fuels. Initially the production will be based on waste lignocellulosics from agricultural, the wood products industry, and muncipal refuse. Is it estimated that there may be 219 million tons of economically recoverable but unused wastes. Thus to meet the 2010 EPAct requirements another 200 to 300 millions tons of dedicated biomass crops may be required. It has been projected that this level of production could theoretically be met on around 12 million ha of cropland at prices less than $2.00/Gigijoules (GJ) by 2005 with modification of USDA farm policies and programs to facilitate biomass crop production and continued support of research and demonstration at a level of about $20 million per year. It is also assumed there would be significant cost sharing on the R&D from the private sector.

The markets for dedicated biomass crops do not exist today, whether the product be biomass power through direct combustion or gasification, or liquid transportation fuels through thermochemical or biochemical conversion of cellulose. There are co-product based examples of renewable biomass energy which account for 3-4 GJ of energy output annually; although these examples rely on residues and wastes from agriculture and the forest products industry and to a small degree corn starch to ethanol. The BFDP strives to not only assure that the dedicated biomass crop technologies are available when and where needed, but also that the infrastructure for production and delivery of the biomass supplies is also developed in tandem. There are five major task areas of the program that support this goal.

Short-Rotation Woody Crop Research

The BFDP has the objective of developing and refining short-rotation woody crop (SRWC) silviculture systems for the production of reliable, low-cost, high quality, sustainable wood for fuel and fiber in the U.S. This task includes the development of equipment systems for improving the efficiency and reducing the cost of producing and harvesting SRWC.

Over the past 15 years the BFDP has supported woody crop research integrating traditional breeding, silvicultural research, and molecular genetics throughout the U.S. In the Pacific Northwest, a well integrated research effort has led to the development of high-yielding (ca. 18 to 26 dry Mg ha^{-1} yr^{-1}) hybrid poplar cultivars adapted to the edaphic, climatic and biological constraints of the region (Wright, 1994). These material are now being planted on over 20,000 hectares with more than double that amount anticipated to be planted within the next 5 years. The progress in yield improvement has not been as dramatic in other parts of the U.S., although much has been learned about silvicultural management of the crops. Nevertheless age 7 yields of the best clones are approaching 12 dry Mg ha^{-1} yr^{-1} in scale-up clone-site trial and up to 18 dry Mg ha^{-1} yr^{-1} in small plots in the North Central Region.

The BFDP is gradually modifying and linking the ongoing research funded at several institutions to create regional woody crop development centers for the North Central Region, the South and the Northeast that are modeled after the successfully integrated efforts in the Pacific Northwest. Each center will optimally involve at a minimum, the integration of silviculture, genetics, plant breeding, entomology and pathology. To the extent possible, new and ongoing research dealing with mechanization and harvesting, economic analysis, environmental studies and demonstrations will be linked with the regional crop development centers as well.

The principal effort of the three regional crop development centers is the selection and breeding of new hybrid poplar plant materials for SRWC production. In the North Central Region, the Iowa State University manages the genetic improvement of hybrid poplar in collaboration with 3 universities, and 2 U.S. Department of Agriculture (USDA) Forest Service Research Stations. Several nurseries and paper companies are contributing to this effort through participation in the North-central hybrid poplar Research Consortium. In the southern part of the U.S., the Mississippi State University is initiating breeding work on hybrid poplar in collaboration with 2 other universities and the USDA Forest Service. Although a consortium has not yet been formally established, 6 paper companies have agreed to assist with germplasm collections, and 3 companies are scheduled to assist with regional trials when new clonal material is produced. In the Northeast, the State University of New York, in close association with the University of Toronto in Canada, is serving as the focal point for the evaluation of willow hybrids in the U.S. Several private companies, primarily utilities, are contributing funds, manpower and lands to support trials of new willow clones. In the Pacific Northwest, a very well integrated effort continues with cooperation between 3 universities and a large number of companies. Now that breeding for the Pacific Northwest is being done by private companies, the University of Washington (UW) is serving as the focal point for the *Populus* Genetic Mapping Cooperative. A closely linked effort is the *Populus* Genetic Transformation Cooperative managed by Oregon State University. Both these efforts transcend the region and have national applicability for all hybrid poplar work. Details of some of the work ongoing at each of these centers was recently described by Tschaplinski and Wright (1994).

To assure that woody crop development centers produce materials that have commercial value, the programs are including the establishment of regional yield and site-adaptability trials of selected genotypes. Here, (1) productivity estimates are being verified on a per unit area basis, (2) adaptability over a broad geographic area is being established, (3) climate-site factors are being evaluated in terms of their impact on pest resistance, and finally (4) technology is being transferred from the research center to subregions where landowners/producers who will be growing the crops can gain "hands on experience" with new production systems. Four regional test sites are ongoing or planned for the North Central Region. Optimally designed tests will evaluate 30-50 new, selected clones per year, planted in large monoclonal blocks over a five-year period. From these tests it is likely that a single highly productive, regionally adapted, pest resistant clone will be identified each year following the initial five years of growth. Results from these efforts will allow better species-site matching and improved productivity estimates from each site (Downing and Tuskan,1995).

Herbaceous Energy Crop Research

The goal of herbaceous energy crop (HEC) research is to develop crops that can be economically produced on a wide variety of sites and readily and practically incorporated into conventional farming operations. Systematic screening studies in a variety of locations have shown that switchgrass can meet this goal for several regions of the U.S. While other species may also be viable candidates, switchgrass has been chosen as the model herbaceous energy crop species for demonstrating the concept. It has a geographical range that covers most of the United States and portions of Canada and Central America and is found in diverse habitats ranging from Midwestern prairies to brackish marshes and open woods. The grass can be used both as a biofuel and as a forage species (although optimal characteristics for each use differ). Switchgrass has several positive environmental attributes including low nutrient use, low pesticide requirements, and a perennial growth habit (McLaughlin, 1994)

Screening studies continue to be used to identify the most promising cultivars and cultural practices. Selected varieties have been utilized in a switchgrass breeding program to further improve production potential. Breeding studies are being integrated with physiological evaluations to develop physiologically based selection criteria for improving yield and identifying promising parents. Classical breeding techniques are being used for rapid improvement of existing varieties with the most desirable phenological and physiological attributes. Tissue culture techniques are being developed to augment classical breeding efforts.

There are currently seven actively funded projects in the herbaceous species task. Six of the projects located in the Southeastern region of the U.S. are collaborating to develop the management techniques, physiological understanding, and breeding technology to establish, produce and harvest switchgrass in an economically and environmentally sound manner. The six projects incorporate production research and regional variety trials at three locations, Texas A&M, Virginia Polytechnic Institute and Auburn University; breeding research at Oklahoma State University; development of techniques to propagate and screen switchgrass through tissue culture techniques at the University of Tennessee; and physiological characterization of switchgrass at ORNL. With ORNL staff facilitating the linkages between the investigators at the different institutions, the set of projects meets the program's objective for having a switchgrass crop development center for the South.

Recent third year results from the variety trials, which are established in Alabama, Texas, Virginia, Tennessee, Kentucky and West Virginia indicate that the select varieties are capable of producing high yields on a variety of site types (McLaughlin, personal communication, May 1995, ORNL). In the third year of growth, average yields of the best varieties ranged from 15.2 to 16.8 dry Mg/ha in 1994 over 19 different locations. Maximum yields of the best varieties ranged from 20.1 to 27.6 dry Mg/ha in 1994. Average yields of all nine of the varieties established in the trials are also good, ranging from 12 to 16.3 dry Mg/ha. Harvesting frequency studies are showing that a double cut system produces highest yields in Alabama and Virginia while a single cut system is best in Texas. The timing of the second cut is very important. Breeding research has gone through 3 cycles with selected plants averaging 60% above non-selected plants. The highest yielding variety continues to be Alamo. Switchgrass is being successfully tissue cultured from nodes, leaves, seeds and florets. Four varieties have been placed in tissue culture. Yields from tissue cultured Alamo varieties established in experimental trials Tennessee have been very high with 1994 yields averaging 22.5 dry Mg/ha and a maximum plot yield of 36.5 dry Mg/ha.

Work in the North Central region is presently limited to a collaborative effort with the USDA Agricultural Research Service at Lincoln Nebraska. The project is conducting yield trials of northern cultivars of switchgrass, evaluating fertilization effects and new herbicides and beginning a breeding effort. If additional money becomes available, switchgrass work in the North Central region would be expanded. A workshop for potential collaborators and stakeholders has been conducted in an effort to define the need and interest in additional switchgrass work in the region.

Environmental Research

The objective of BFDP's environmental research is to develop site-specific regional data related to environmental parameters such as biodiversity, chemical fate, soil chemistry and carbon content, erosion and surface water runoff, and plantation design which would facilitate the implementation of SRWC plantings at the field, landscape, and regional levels as to ensure sustainable, environmentally acceptable feedstock production.

Since the beginning of the BFDP, environmental acceptability and sustainability have been part of the selection criteria for identification of promising crops and production systems. Perennial crops have been favored over annual crops because of their ability to provide soil stability, nutrient retention, and reduced agrochemical requirements. Tree crops with 5-10 year rotations have been favored over very short 1-3 year rotations, in part, to reduce nutrient drainage from soils and the potential for soil compaction effects from frequent harvesting. Fertilization studies designed to consider effects on water quality have demonstrated that application procedures can minimize water quality impacts and provide more cost-effective impacts on growth if applied on an as needed basis during the rotation rather than in a large initial application (Van Miegroet *et al*, 1994). Bird and small mammal surveys have been conducted in commercial and experimental plots to address biodiversity compared to traditional land uses. Results from some of these studies have shown switchgrass plantings can serve as habitat for some Prairie songbirds which are dwindling in population numbers and that woody crop plantations established next to forestland allow internal forest species to extend their habitat range to the edge of the forested area (Tolbert and Downing, 1995). Where woody crops provide the only wood cover in a farm area, preliminary data suggests they will be used by a variety of birds.

Existing and proposed biomass plantings at demonstration and industrial sites are providing the opportunity to expand the existing data needed to address environmental questions associated with biodiversity, chemical fate, erosion and surface water movement, and soil chemistry in a number of regions with the potential for biomass crop production (Tolbert and Downing, 1995). A small scale study is underway with the National Audubon Society to monitor groundwater drawdown beneath demonstration hybrid poplar plantings in Minnesota, because of concerns about potential effects on nearby wetlands. Comparisons of large-scale plantings with adjacent or nearby natural areas, wetlands, managed forests, grasslands, and agricultural sites will provide data to determine if location of biomass crops can enhance the biodiversity of existing landscapes. Some flexibility will exist to design experimental SRWC plantings to fit within existing landscape features to address the premise that plantation design and silvicultural options can enhance SRWC value for wildlife. Contingent on program funding levels, plans include monitoring various SRWC management options such as interplanting trees with a cover crop, planting specific tree or cover crops adjacent to SRWC plantations, and planting multiple commercial species to determine if SRWC can increase biodiversity.

The fate of chemicals, including pesticides, herbicides, and fertilizers, are an important component of developing environmentally acceptable biomass crop systems. There are currently no field data specific to biomass crops which addresses how environmental parameters such as soil type, species, cover crops, or climate influence movement of chemicals within the soil and the release of chemicals into soils and groundwater. The effect of these physical parameters on the type and quantity of chemicals which migrate from production sites and their ultimate effects on surface water quality are also unknown. The BFDP is currently examining some water quality issues using small watershed models in collaboration with Purdue University. Collaborative work initiated in fall 1994 with the Tennessee Valley Authority in northern Mississippi, western Tennessee and northern Alabama (with Alabama A&M involved) will assess the fate of chemicals applied to SRWC with and without a cover crop, switchgrass, and corn plantings. Studies in Minnesota which were initiated in 1994 involving the USDA Forest Service and the University of Minnesota are looking at nutrients, pesticides and herbicides in soil and groundwater. Additional field studies, preferably linked with each woody and herbaceous crop development center, are needed to estimate the above parameters under the wide variety of physical boundaries within and among regions.

The third area of environmental research is the sequestration of carbon in soils by biomass crops. Carbon sequestration in soil has been predicted to be an important means of reducing greenhouse gases. Assessing soil carbon changes is essential in developing greenhouse gas balances and determining the economic importance of potential carbon sequestration tax credits. Studies on CRP sites planted to switchgrass have shown that soil carbon sequestration may be as much as 1 Mt C/ha/year over the first 5 years in the top 100 cm of soil (McLaughlin, 1994). New studies collecting soil chemistry data at multiple sites in different regions will provide information on potential differences in soil carbon sequestration rates as a function of soil type, tree or grass species, management systems, harvesting regimes, and climate. The results of soil carbon studies can contribute to consideration of issues related to carbon tax credits.

The BFDP's Environmental Task is attempting to provide a well-documented, technically sound data base on environmental impacts of various silvicultural options. This information can then be used on a region, site, and species basis to document the sustainability and environmental benefits of energy crops as currently envisioned. These data will also provide a baseline and basis for improving the cultural systems to enhance the sustainability of energy crops. It is anticipated that with adequate funding at least five years will be required to adequately quantify changes in soil carbon, chemical composition of groundwater and surface water runoff, and biodiversity associated with representative energy crop sites in the U.S.

Systems Integration and Analysis

The objective of the Systems Integration and Analysis task is to assess the environmental and economic costs, benefits, and trade-offs associated with various SRWC silviculture systems for life cycle analysis and to determine carbon offset and carbon credits from SRWC that would allow trading and/or purchase of such credits.

Economic analyses of SRWC production systems have been a part of the BFDP program since program inception and have become increasingly sophisticated as our understanding of SRWC production technology has matured. Preliminary evaluations analyzed the variation in production costs with respect to resource characteristics and economic conditions and examined the nature of potential trade-offs in system design and operation. Some of the early studies were concerned with determining optimal rotations, yield-response to fertilization, and whether certain management options, such as irrigation, were likely to be cost-effective. As better SRWC information and data became available, these studies were refined and new studies undertaken to look at SRWC economics more from the perspective of potential developers. Farm level studies were conducted (English *et al* 1991) and preliminary regional supply curves estimated (Graham and Downing, 1995). Fuel cycle studies and assessments of carbon flows from SRWC plantings were also undertaken (Perlack *et al,* 1992). Recently a complete accounting of hybrid poplar and switchgrass production costs has been documented, though not yet published.

Several attempts have been made to estimate the potential supplies of biomass crops that could be available on a national scale at prices that would provide the landowners a profit and yet be feasible for use as an energy feedstock. The most comprehensive effort has been undertaken in collaboration with USDA, Environmental Protection Agency, and the Office of Science and Technology Policy. Results are being reported by others at this conference (Roningen et. al., 1995), but the bottom line is that if energy useres could pay $2.00 GJ, then energy crops could be competitive on about 12 million hectares. However, with coal available at less than $1.25 GJ, the supplies of biomass crops that could be competitive with coal, using conventional conversion technologies are very limited. Work is currently also underway to examine in a more detailed level the potential supplies of biomass crops that would be available in 11 selected Midwestern and southern states. Environmental and economic drivers are being linked in the analysis efforts.

Scale-up, Feasibility and Demonstration

The goal of this task is to facilitate commercialization of integrated biomass energy systems. The objectives of this task are to gather, assess, and disseminate information on operational costs, requirements, risk and other considerations in planting and developing entire integrated commercial supply systems of biomass crops. The task extends energy crop research results to successively larger planting blocks from 30 to 300 acres; 1000 acres at a time. A major component of the task involves synthesizing relevant information from herbaceous and woody crop development, environmental research, and systems integration and analysis components of the BFDP and making it available to industries developing or considering biomass facilities.

The BFDP is supporting one major scale-up project, a hybrid poplar project administered by the WesMin RC&D near Alexandria, Minnesota. One thousand acres were planted in late May 1994 following early spring land preparation. All land was enrolled in the Conservation Reserve Program (CRP) and qualified for 5-year contract extensions. Seven hundred thousand hybrid poplar cuttings were produced and planted by several private nurseries. Some plantings were successful and have been replanted this spring along with an additional 1000 acres. Lessons learned by the participants included the importance of fall site preparation, site selection, specifications for planting stock, and the importance of good nursery management of the planting stock. Valuable information on costs, labor and issues highlighted by the experience are being summarized in a document soon to be available to the public (Downing *et al*, 1995). Some of that information is summarized in the presentation by Kroll and Downing (1995).

The BFDP is working with industries and landowners considering electricity and liquid fuel produced from biomass by participating in 10 DOE-funded feasibility studies entitled "Economic Development through Biomass Systems Integration". The benefits expected to accrue to the DOE biomass programs are an increased understanding of how potential users of energy crops expect to evaluate dedicated feedstock supply systems and the kinds of information needed for the operational phase. The BFDP participation adds an agricultural perspective to the feasibility study groups and provides access to results of energy crop research performed for the BFDP since 1978.

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IS THERE A NEED FOR SITE PRODUCTIVITY FUNCTIONS FOR SHORT-ROTATION WOODY CROP PLANTINGS?

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Abstract

For over a decade, researchers have used small-scale research plots to assist development and selection of high yielding, pest-resistant clones of fast-growing hardwoods such as hybrid poplar (*Populus* spp.). Substantial advances have been made in the techniques and criteria for screening species and selecting clones. Data from these research plots indicate that the ultimate performance of selected clones is dependent upon variable factors in the environment. Until now, researchers could only determine the suitability of a given site for such clones, not the actual yield potential of the site. Recently in the north central United States, several clones were planted on larger-than-research-scale plots on private land recontracted under the Conservation Reserve Program (CRP). The historical database could not provide a framework which would allow producers to predict the yield potential of a particular clone on a specific site. Through a systematic combination of clonal trials on experimental research-scale plots and operational plantings on 50 to 100 acre agricultural-scale field plots, it may be possible to develop yield functions or site quality equations which would predict biomass yields at rotation for selected clones. Such estimates will (1) reduce the probability of planting failure, (2) allow maximum expression of the genetic potential of selected superior clones, and thus (3) facilitate accurate economic planning for both the producer and conversion facility manager.

Introduction

Through financial cooperation and integrated research a hybrid poplar (*Populus* spp.) plantation network was established in 1987 in the upper north-central United States. There have been several research objectives related to the establishment and monitoring of this network over the last 8 years. The most important may have been the screening and identification of hybrid poplar clones for operational use in Minnesota, North Dakota, South Dakota, and Wisconsin. Through the screening process, researchers have worked to develop accurate tools with which to estimate yield potential of selected clones on these particular sites. In addition to clonal screening, these plantations have been used to characterize pest resistance in the studied clones and to categorize environmental factors that influence growth.

It is known that two major environmental factors that determine yield potential are the edaphic and climatic characteristics of the selected sites. Although many crop management factors like weed control affect mortality and eventual productivity at rotation age, the soil and climatic factors are generally a matter of initial site selection rather than site modification. Thus, site selection becomes an important contributor to final plant productivity. This paper addresses three aspects of site selection and characterization related to short-rotation woody culture (SRWC) production. The first, consists of a review of historical data and literature dealing with soil and climate factors related to SRWC. The second aspect of this paper outlines potential application of site productivity functions from a hybrid poplar producer and hybrid poplar consumer perspective. And the third, presents a framework for the development of site productivity functions based on estimates of the number of acres, test sites, and clones to test on each site required to create robust prediction equations.

Because of the importance of the north-central U.S. to the development of biomass energy crops in the U.S. and because of the prominent role hybrid poplar play in this development, this region will be used in this paper as a model for the development of similar productivity functions in other regions and for other species of SRWC.

Historical Data

Several authors over the past 10 years have published criteria for site selection for hybrid poplars (Heilmann *et al.* 1991, Arbor Day Foundation 1993, Hansen *et al.* 1993). Site selection criteria for eastern cottonwood (*Populus deltoides* Bart.) were developed nearly 35 years ago (Broadfoot 1960). All of these criteria describe the need for moderate textured, well-drained soils with moderately high fertility, 3-8% organic matter and soil pH between 5.6 and 7.8. High water availability through either high water holding capacity or high water table are also required, though sites with prolonged flooding or standing water should be avoided. These criteria are designed mainly to eliminate sites that (1) do not provide minimal site requirements for soil texture, fertility, or organic matter content or (2) exceed threshold characteristics such as pH or slope. Although these criteria are important, they do not establish a relationship between site "quality" and ultimate hybrid poplar productivity. Such a relationship would (1) decrease production risk and supply uncertainty for producers and consumers, respectively, (2) ensure reliable productivity and yield from selected clones, (3) assist in determination of number of sites needed of a particular "quality" to attain an overall production level and (4) provide a reliable basis with which to determine alternative economic returns to different scales of production. The need for a more refined quantitative description of this relationship is the basis of this paper.

There is little literature and data available describing the relationship of hybrid poplar productivity to soils and climate within any SRWC plantations. Hansen *et al.* (1995), reporting on 130 acres of demonstration plantations in the north-central U.S., states that average productivity in 7- and 8-year-old hybrid poplar plantations equaled 3.3 dry tons per acre per year (TAY), ranged up to 4.6 TAY for the best clone at the best site, and surpassed 8.0 TAY on the best plot. Figure 1 demonstrates the effect of site and clonal selection on biomass production for 6-year-old plantations (Hansen *et al.* 1993). Although there was little difference in production within sites among clones, there was a substantial difference in production between sites, illustrating the importance of and opportunity for site selection to attain consistently high yields in future plantings (Hansen *et al.* 1993). Hansen *et al.* (1993) did report that water availability was a major factor in determining biomass production on a given site.

Hansen *et al.* (1993) also showed no definitive results to suggest that a particular clone would be recommended at one site or another. A regression equation: total tree dry weight = -1.67 * 0.23 (Diameter at Breast Height^2), accounted for 98% of the total variation in biomass productivity and did not significantly vary among clones. Similar results were obtained by Tuskan and Rensema (1990) where total tree dry weight for four hybrid poplar clones grown in North Dakota could be reliably predicted by a single regression equation. Hansen *et al.* (1995) did note that the regression coefficients did vary significantly by site, supporting the hypothesis that there is a relationship between site quality and hybrid poplar productivity.

Berguson (1992) examined the north-central plantation network with the objectives to characterize soils within the network and to investigate the relationship between plantation productivity to soil and climate characteristics. Twenty-three sampling sites were chosen in Minnesota, Wisconsin, North Dakota, and South Dakota. Complete soil profiles were described according to Soil Conservation Service (SCS) standards. Soil bulk densities, organic matter content, and portion of gravel, sand, silt and clay were determined. Complete chemical analyses were performed. Particle size distribution and organic matter content were used to estimate the available water capacity by regression equation. Climate information was acquired from the National Oceanic and Atmospheric Administration (NOAA) data obtained nearest each planting site. Monthly average high and low temperatures, total annual rainfall and cooling degree days were included in this database.

The results of this assessment indicated that although soil characteristics varied widely across the network there was no relationship between any of the measured soil characteristics and poplar productivity. Berguson (1992) did note that growth, stand age, and soil characteristics were confounded among sampled sites. This confounding may have obscured the effect of soil water holding capacity, total available moisture or soil texture on tree biomass. After accounting for stand age, average cooling degree days was found to be positively correlated with mean tree dry weight. The R^2 value indicated that 91 percent of the total variation in tree dry weight was explained by differences in averaging cooling days among sites. Berguson concluded that plantation productivity relationships with soil and climate characteristics would become stronger and more evident over time as plantation stands matured. Berguson recommended that the analysis could be improved by (1) obtaining daily temperature and growing degree days for all sites, (2) improving the precision of precipitation estimates, (3) using exponential weighing of soil properties, (4) collecting tree growth measurements at other sites, and (5) adding total runoff input by analyzing topography of land surrounding the sites.

Berguson (1994), through funding provided by the Electric Power Research Institute (EPRI), evaluated the land suitability of soils and climate for poplar production within the north central U.S. As an indicator of site quality, Berguson relied on the United States Department of Agriculture Soil Conservation Service (USDA-SCS) land capability classes to predict growth. The analyses were done with U.S. Forest Service Forest Inventory and Analyses (FIA) unit boundaries. Division of some of the units was necessary to provide a more detailed evaluation of soil suitability within the units. From the data presented in this paper, and as noted by Graham and Downing (1995), it is apparent that there is no relationship between SCS land capability class and poplar productivity. Heimlich (1994) confirms this as well. Furthermore, information on land rent, as provided by the Conservation Reserve Program (CRP), was not related to hybrid poplar productivity (see Table 8, Berguson 1994). Berguson does conclude that MN-AB MN-NP and MI-WUP units (Figure 2) have less potential production due to lower quality soils and low percentage of agricultural land. MN-P2 and MN-P3, and WI-SE units are considered highly productive in general but any drought-risk areas may pose difficulty in making site specific clonal selections (see Figure 2).

Potential Applications of Site Productivity Functions

Reliable site productivity functions (that is, equations that would predict final mean annual dry weight at rotation based on edaphic and climatic characteristics of the selected site) would allow individual landowners to assess the potential biomass crops would offer as an alternative crop for their available land. This type of information would lead to more accurate projections of economic return from these lands. In addition, a consumer in a market for SRWC wood could more accurately plan annual feedstock acquisitions based on site productivity functions. For example, if a conversion facility requires 500 tons per day and the plant operates for 200 days per year, then 10,000 tons per year are needed. This would require harvesting 2000 acres per year if productivity is projected to be 5 TAY. If these plantations were managed on a 10 year rotation, the facility would need to rely on a 20,000 acre "fibershed" base. Alternatively, if sites could be identified that yield 7.5 TAY, then the total number of acres committed to the conversion facility could be reduced to ca. 13,000 acres. Accurate site productivity functions would permit conversion facility managers (1) to select the most productive sites within a given supply radius or (2) to project biomass yields from available land if site selection was not possible. Thus, both the landowner and conversion facility manager would benefit from reliable site productivity functions.

The ability to provide site productivity functions and thus site indices to predict final biomass yields on larger scales can only be accomplished through continued refinement and collection of all possible environmental determinants of growth. Although previous studies were unable to detect relationships between direct (e.g. soil attributes) or indirect (e.g. land rent values) site characteristics and measured productivity, Berguson and Hansen both noted the limited number of sites available for conducting such studies.

Recommendations for the Development of Site Productivity Functions

There are three areas for continued and new research. Accomplishing these goals over the next 5-10 years would (1) reduce the probability of planting failure, (2) allow maximum expression of the genetic potential of selected superior clones, and thus (3) facilitate accurate economic planning for both the producer and conversion facility manager.

First, measurement of the current hybrid poplar plantation network must continue through age 12 (currently age 9) in order to completely understand the actual yield potential at these sites, as well as verify the developed biomass regression equation. Information from these established sites will provide 1) measurements of mean annual increment which had not culminated on the study sites, 2) defined optimal rotation ages and yields of intensively cultured hybrid poplar, and 3) a clear relationship between foliar N and plot yield based on a significant decline in foliar N observed in the last year of study.

Second, in the spring of 1994, 3 clones of hybrid poplar were planted on 1000 acres of CRP land near Alexandria, MN. Intensive agricultural production budget information is currently being tracked for each year of production through harvest. This information is the only production-scale budget information being assembled on hybrid poplar. Production budget data such as these will provide economic information at the farm or producer scale. It will also provide sufficient information needed to establish pricing information for a potentially developing market for energy or increased hardwood market in the pulp and paper industry (Downing *et al.* 1994).

The most definitive data currently being assembled and tracked over time are the relationships of 28 soils on 14 CRP sites across the 1000 acres mentioned above and the specific number of plants and identified clones of hybrid poplar planted. This information will provide valuable yield information on sites where clones and soil types as well as SCS soil capability classes are mapped with scaled precision (Downing *et al.* 1994). This information will be augmented by data collected from a second 1000 acre planting established in May 1995. The growth and performance data on these sites will need to continue to be tracked through one full rotation. While the information will contribute to the data base needed to develop site productivity functions, it is limited to one climatic zone.

Finally, to permit robust statistical testing of the relationship between site characteristics and biomass productivity we propose the establishment of a regional site quality characterization study for the north-central U.S. This study would involve 4-8 test sites within each of three suitable subregions noted by Berguson (1995). At each site four genetically-diverse, highly-productive, selected hybrid poplar clones should be planted in 12 x 12 clonal blocks replicated four times per site. Establishment and maintenance procedures should be based on standard protocols outlined by Hansen *et al.* (1993). The entire study should be replicated in two successive years to account for variable climatic conditions. Finally, the study should be maintained for the full rotation length of 8-10 years. Annual incremental productivity should be based on the regression equations developed by Hansen *et al.* (1995), with the final productivity values based on destructive sampling and direct measures of dry weight. Weather stations should be established at each location and a complete assessment of soil properties should be conducted before and after completion of the study. This information should be combined with all additional data available on environmental factors and growth rates from other regional experimental, pre-operational, and commercial plantations to create a reliable site productivity function for the north central U.S.

Conclusions

Accurate site productivity functions would have utility to both potential producers and consumers of SRWC biomass. The establishment of systematically selected research plots for the development of site productivity functions will allow (1) a robust examination of the relationship between site characteristics and biomass productivity, and if justified, (2) the development of such functions. Data used in the correlation analyses would be collected at each site, as opposed to near available source, to assure accuracy. Furthermore, existing research plots and pre-operational plots in the region will be leveraged against the new plots to help validate the tested relationships.

Through funding provided by the U.S. Department of Energy's (DOE) Biofuels Feedstock Development Program (BFDP) and the Legislative Commission on Minnesota Resources (LCMR) from 1987 through 1991, the United States Forest Service (USFS) and University of Minnesota at Crookston established a hybrid poplar plantation network.

Figure1. Effect of site and clonal selection on biomass production. From Hansen et al., 1993) (6-year old plantations)

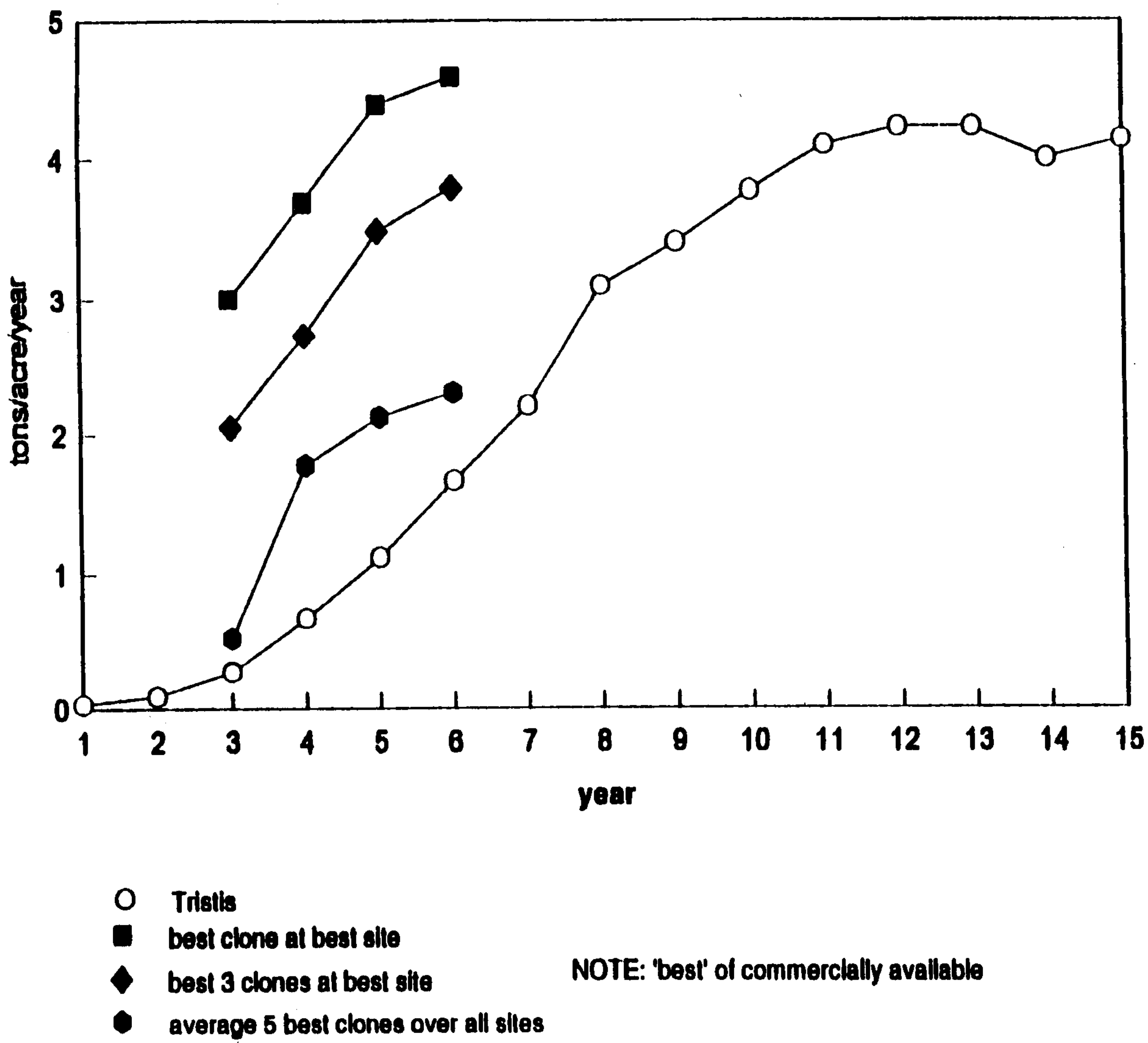
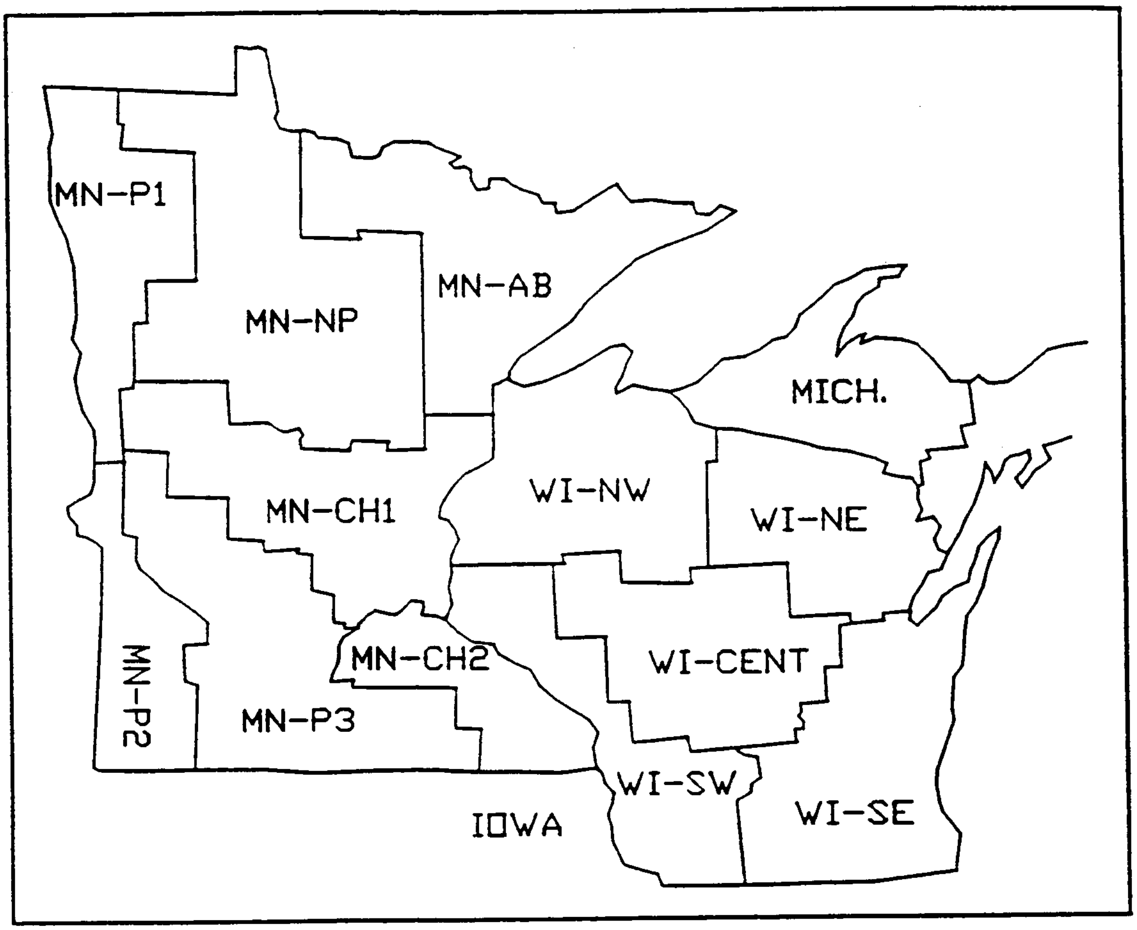


Figure 2. Forest Inventory and Analysis (FIA) units and subunits used in analysis. (From Berguson 1994)



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VARIABILITY IN THE COMPOSITION OF SHORT ROTATION WOODY FEEDSTOCKS

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Abstract

This paper discusses the variability in chemical composition caused by clonal, geographical, and environmental effects on short rotation woody feedstocks, mainly hybrid clones of poplar. The concentrations of major and minor components have been determined by chemical analysis and pyrolysis molecular beam mass spectrometry (PY-MBMS). The chemical composition was determined for a sample set consisting of debarked wood chips from three clones of *deltoides x nigra* (DN) and one clone of *tristis x balsamifera* that were grown on four replicate plots at two locations in Wisconsin. The composition of the wood chips determined by chemical analysis and Py-MBMS showed that the *tristis* clone was significantly different from that of all the DN clones. The composition of the DN clones studied in this sample set were relatively similar to other hybrid poplar samples that have been analyzed over the past three years. The level of compositional variation due to clonal, geographical and environmental factors observed in short rotation woody species to date indicates that they are a consistent and stable feedstock for biofuels production.

The effects of storage on different short rotation woody crops has been studied. Results of the analysis of fresh and stored hybrid poplar using traditional wet chemical analysis showed differences in the chemical composition of the feedstocks because of storage. Also presented are results from a rapid analytical technique using pyrolysis-mass spectrometry combined with multivariate statistical analysis to assess the influence of storage on the composition of different short rotation feedstocks. Because of the rapid nature of this technique, a large number of samples could be screened to determine the extent of degradation throughout the piles. The application of this technique to the samples in this study indicated changes in chemical composition occurred during the storage period.

Introduction

The U.S. Department of Energy has embarked on a major program to produce liquid fuels and chemicals from renewable resources by the year 2000. As part of this objective, the production of liquid fuels such as ethanol and thermochemical fuels (ethers) from terrestrial biomass resources has been a major focal point. The objective of the process interaction task in the Terrestrial Biomass Feedstock Interface Project of the NREL Biofuels Program is to assess available and developing lignocellulosic feedstocks for selection of suitable candidates for conversion into ethanol and other biofuels. The data developed in this task will also be used to guide the feedstock development program to produce improved feedstocks. Both literature and experimental data are being generated for representative feeds that have the potential to supply on a concentrated regional or national basis a significant fraction of our energy needs. Integral to the selection is the assessment of the environmental acceptability of the feedstock as a sustainable basis for fuels production.

Methods and Procedures

Samples

Samples of fresh and stored hybrid poplar (*Populus deltoides x nigra var.* Caudina) whole-tree chips, were supplied to NREL researchers by the subcontractors of the NREL Terrestrial Biomass Feedstock Interface Project. The hybrid poplar trees were harvested from section # 11 of Rocksburg Township, Pennington County, Minnesota. The trees were transported for processing at the Northwest Experimental Station in Crookston, Minnesota. The hybrid poplar trees were reported to have been planted in either 1984 or 1985. About 22% of the hybrid poplar trees harvested were infected with Septoria canker (*Septoria musina)*, but there was no evidence of secondary fungal or bacterial infections. Samples were taken from the centers of the piles after 3.25, 6.5, 13, and 26 weeks of unprotected outside storage and compared to fresh biomass. Additionally, some samples were obtained from different areas throughout the pile after 26 weeks of storage. All samples used were ground in a Wiley mill and sieved to -20/+80 mesh size.

Other samples studied consisted of debarked hybrid poplar wood chips provided by the United States Department of Agriculture-Forest Service (USDA-FS) North Central Forestry Experiment Station at Rhinelander, Wisconsin Included in the sample set were three clones of *deltoides x nigra* (DN-17, DN-182, and DN-34) and one clone of *tristis x balsamifera* (NC-5260), that were grown at two locations in Wisconsin (Ashland and Mondovi) on four replicate plots at each location. The three DN clones gave similar yields at each location while the NC clone was characterized as a much lower yielding clone whose survival rate was also not as good as the DN clones. The two locations studied are characterized as being high yielding (Mondovi) and low yielding (Ashland). The lower yields result from a shorter growing season (about two weeks) caused by the more northerly location of Ashland, Wisconsin Seven years after establishment the yields were; DN-34, 1.0 and 3.4 tons/acre/y; DN-17, 2.2 and 4.0 tons/acre/y; DN-182,1.2 and 4.0 tons/acre/y, respectively at the Ashland and Mondovi locations. The yield of the NC clone is believed to be less than 1 ton/acre/yr (the actual yield was not measured); although its yield has started to increase in the trees remaining after seven years.

Compositional Analysis
The procedure used was previously tested in a round robin sponsored by the International Energy Agency (IEA) that showed it was applicable to both woody and herbaceous feedstocks (1). The procedure used involves ethanol extraction of the biomass, followed by hydrolysis of the extracted material to determine lignin content and to break down the polysaccharides into their constituent monosaccharides. The monosaccharides are then converted to their respective alditol acetates prior to gas chromatographic (GC) quantitation. The lignin content was estimated by adding the acid-soluble lignin content to the acid-insoluble residue amount and then subtracting the ash content of the acid-insoluble residue. Sufficient replication was included in these analyses so that the data could be evaluated statistically to identify those changes that were significant at the 95% confidence level.

Rapid Pyrolysis of Biomass Feedstocks
Frozen biomass feedstock samples (-20/+80 mesh) were thawed and weighed (25-30 mg) in quartz boats in triplicates. The samples were pyrolyzed in a single-stage pyrolysis quench reactor at 600°C and atmospheric pressure. The reactor consisted of a quartz tube (2.5 cm diameter) with helium flowing through at 5 L/min(STP). The reactor tube was interfaced with the orifice of a homebuilt molecular beam mass spectrometer (MBMS) based on a Extrel™ Model TQMS C50 mass spectrometer for pyrolysis vapor analysis (2). Total pyrolysis time was 90 s and mass spectral data were acquired on a Teknivent Vector 2™ data acquisition system interfaced to a personal computer. Masses 15-300 Da were monitored in real time during the pyrolysis period.

Multivariate Analysis of Data
Mass spectral data acquired from the pyrolysis process were analyzed by multivariate statistical techniques. The data were first normalized to the total ion current to account for the sample size variation. Data reduction and resolution were carried out on the normalized data using the Interactive Self-modeling Multivariate Analysis (ISMA) program (3). The correlation around the mean matrix was used to select the significant number of factors for resolution of the mass spectral data into compound classes. Factor scores from the analysis were presented in two-dimensional plots to show compositional differences between various biomass materials. Materials with similar mass spectral intensities form clusters in the factor space.

Results and Discussion

Effect of Clonal and Environmental Factors
The data shown in Table 1 represents the mean compositions of all samples of each clone that were analyzed, including samples from both the Ashland and Mondovi locations. Except for the DN-34 clone, only one of the replicate plots from each location was analyzed. For DN-34, a sample from each of the four replicate plots at the Ashland location was analyzed, and a sample from two of the replicate plots at the Mondovi location was analyzed. The variability in concentration for each of the components in each clone is indicated. This value is the pooled standard deviation, calculated by pooling the standard deviations from replicate analyses of each sample with the standard deviation of the mean values for each clone. In general the pooled standard deviation appeared to be about twice the standard deviation due to the analytical irreproducibilities alone. Inspection of the results in Table 1 shows that the compositions of all the DN clones were similar. There were no statistically significant

differences (at the 95% confidence level) in any of the components. There was, however, a significant difference between the DN clones and the NC-5260 clone. Taking all of the DN samples as members of the same sample population, statistically significant differences were seen between the NC clone and the DN clones in the extractives, ash, lignin, xylan and glucan components.

Table 1. Compositions (% of oven-dried weight) of Debarked Wood Chips from Hybrid Poplar Clones Grown in Wisconsin.

	DN-17	DN-182	DN-34	NC-5260
Extractives	3.6 ± 0.7	2.9 ± 0.4	2.6 ± 0.7	4.1± 0.5
Ash	0.9 ± 0.1	0.8 ± 0.1	0.7 ± 0.1	0.5 ± 0.1
Lignin	23.3 ± 0.5	23.5 ± 0.2	23.8 ± 0.4	21.3 ± 0.4
Arabinan	0.5 ± 0.1	0.5 ± 0.1	0.6 ± 0.1	0.6 ± 0.1
Xylan	17.6 ± 1.5	17.2 ± 0.5	17.7 ± 0.6	16.3 ± 0.5
Mannan	3.0 ± 0.3	2.7 ± 0.1	2.8 ± 0.2	2.9 ± 0.2
Galactan	0.7 ± 0.1	0.7 ± 0.1	0.7 ± 0.1	0.7 ± 0.1
Glucan	43.7 ± 0.5	43.9 ± 2.3	43.4 ± 1.8	46.2 ± 1.7
Mass Closure[1]	99 ± 1	98 ± 2	98 ± 2	99 ± 1

[1] Mass closure including 4% for the uronic acids and 2% for the acetyl components not determined by analysis.

Figure 1 graphically presents the data for all of the samples subjected to compositional analysis. Again it is clear that the samples of NC-5260 are significantly different in composition. Here the compositions of samples from replicate plots of DN-34 grown at the same location are indicated by a solid line drawn between four samples from Ashland and by dashed line between the two samples from Mondovi. The error bars in this figure indicate the analytical irreproducibility (± one standard deviation) in determining the glucan and lignin contents of these samples.

Table 2 shows the difference in composition between the NC-5260 clone and the population of DN clones, and the levels necessary for those differences to be statistically significant at the 90% and 95% confidence levels. The components that differed significantly at least the 90% confidence level are underlined. The NC-5260 clone was significantly different (at the 95% confidence level) from the population of DN clones studied, because of its lower ash, lignin, and xylan contents, and because of its higher extractives contents. Glucan content was significantly higher in the NC-5260 clone, however, only at the 90% confidence level. Evidently, for the samples studied, the origin of the clonal material has a greater influence on determining composition than does locations despite the strong effect of location on biomass yield.

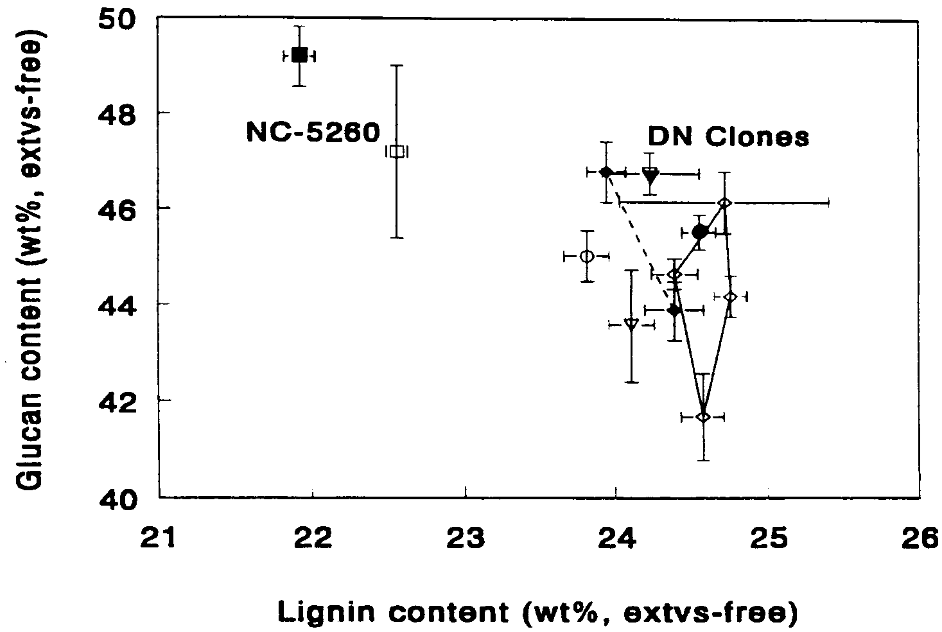

Figure 1. Compositional Variability in Debarked Wood Chips from Different Hybrid Poplar Clones Grown in Two Locations. DN-17 (○), DN-34 (◇), DN-182 (▽), NC-5260 (□). Open Symbols, Ashland, Wisconsin Filled Symbols, Mondovi, Wisconsin. Error bars indicate the analytical error (± one standard deviation).

Figure 2 shows the data obtained by Py-MBMS analysis of the whole sample set. The advantage of the Py-MBMS technique is its rapid nature that allows for a large number of samples to be screened in a short time when compared to traditional wet chemical analysis. Using the Py-MBMS method, all the samples, including plot replicates, could be screened in one day. The same trends are observed in the whole sample set as were observed in the selected samples analyzed for chemical composition, i.e., that samples from replicate plots of the same clone grown at the same location were indistinguishable from each other, that samples of the same clone grown at different locations were very similar, and that all of the DN clones were very similar to each other but significantly different from the NC-5260 clone. Inspection of the factor loadings on factor 2, the factor mostly responsible for resolving these samples into two groups, showed that this factor correlated positively with lignin content and negatively with carbohydrate content. Thus the data from Py-MBMS agreed with compositional analysis data, indicating that the NC clone was higher in carbohydrates and lower in lignin.

Table 2. Difference in Composition (%, oven-dried weight basis) Between of Debarked Wood Chips from Hybrid Poplar Clones NC-5260 and All DN Clones and Significance Levels. The components that differed significantly at least at the 90% confidence level are underlined.

	Difference (%) in Composition NC-5260 - DN clones	90% Confidence Level	95% Confidence Level
Extractives	1.3	0.9	1.2
Ash	-0.21	0.17	0.20
Lignin	-2.3	0.5	0.7
Arabinan	0.06	0.10	0.12
Xylan	-1.3	1.0	1.2
Mannan	0.09	0.29	0.35
Galactan	0.03	0.12	0.15
Glucan	2.7	2.3	2.9

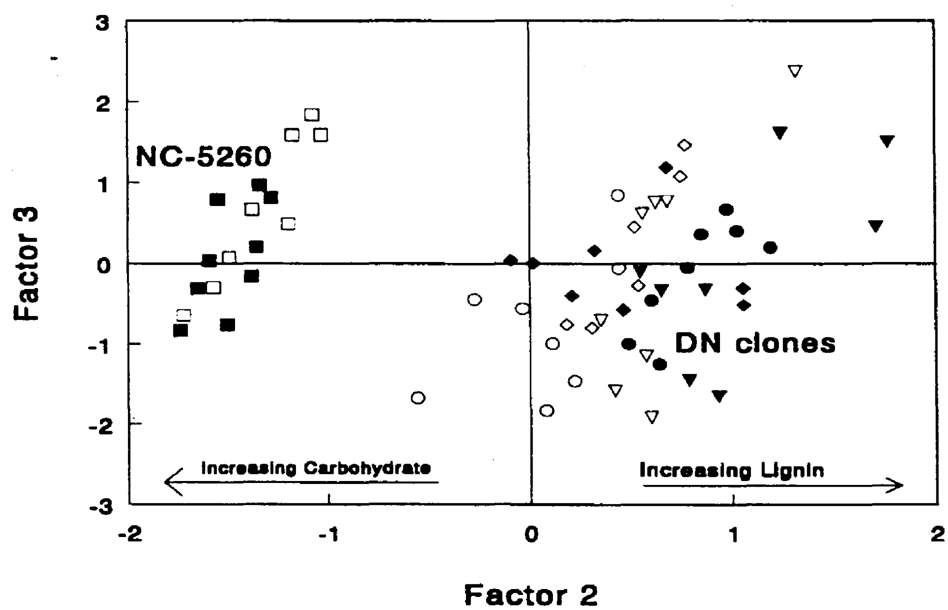

Figure 2. Factor-score plot of Py-MBMS data of different hybrid poplar clones grown in two locations. DN-17 (○), DN-34 (◇), DN-182 (▽), NC-5260 (□). Open symbols and filled symbols represent samples harvested from Ashland, Wisconsin and Mondovi, Wisconsin, respectively.

Effect of Storage

Table 3 presents the chemical composition of hybrid poplar samples harvested in December and April. There were small differences in the day zero compositional data for the two different harvests, the greatest difference was that the extractives content was almost 2% (6.6% versus 4.8%) lower in the April harvest than the December harvest. After storing the material harvested in December, the largest significant changes were observed in the extractives and the xylan content. The largest significant changes observed in the stored material from the April harvest were measured in the lignin and xylan contents. Possible explanations for the increased xylan contents are: degradation, which caused decreases in some components resulting in higher levels of the remaining components; a contribution to the xylan content from the hyphae of fungi which may have started to flourish; or that the time zero materials taken for analysis were not representative of the center of the pile. Previous studies have indicated that white and soft rot fungal degradation will remove cell wall components preferentially and these organisms are known to attack wood that is stored outdoors (4). Additional replicate analyses confirmed the increases in xylan content reported here, however, the cause of the increase has not been positively identified.

Multivariate analysis was performed on Py-MBMS data of the December harvest of hybrid poplar chip pile that was stored outside unprotected for 26 weeks. Factor analysis of the chip pile data revealed four significant factors that accounted for 86% of the observed variance in the data. The samples were classified into three main groups as shown by the clusters in the factor space (Figure 3). The main difference between the three clusters, labeled A, B, and C, was determined to be due to the relative lignin content of the three different groups of samples. The samples in cluster C were, in addition to the relative lignin content, also higher in phenolic ester pyrolysis products. A "computer-generated" factor spectrum of the component responsible for separating the cluster C sample from the other samples contained a peak at m/z=120. The m/z=120 peak, believed to arise from phenolic esters, is mostly found in herbaceous biomass pyrolysis products and its appearance in hybrid poplar pyrolysis products cannot be easily explained. If this peak is excluded from the factor analysis routine, then the Group C sample is incorporated in the cluster of Group A samples which suggests similarity in chemical composition with fresh samples. However, the workers in the field reported that some small twigs in the wood chip pile were leafing out and some logs were also producing leaves after 26 weeks of storage. It could be that these leaves contaminated the 26-week-old wood sample and resulted in the strong m/z 120 during the pyrolysis of the feedstocks.

The clusters, A and B, are distinguished from each other by their relative lignin and carbohydrate contents. The samples in cluster A of the factor-score plot (which would include the 26 week sample if mass 120 is removed from the multivariate analysis) contain a higher concentration of lignin than the cluster B samples. The cluster B samples were determined to be high in carbohydrates. These differences could be attributed to microbial degradation of the samples. The high carbohydrate content of the cluster B samples, all of which were taken after dissection of the piles after 26 weeks of storage, indicate attack by fungi that preferentially degraded the lignin component of the cell wall. The clustering of the surface and other samples taken from the interior of the pile with the time zero sample in cluster A suggests that there are no significant differences between the chemical composition of the time zero samples and the other samples contained in Group A. This phenomena is quite different from the American sycamore and black locust chip piles (data not shown) where the pile degradation was confined to the surface crust of the pile.

Table 3. Differences Observed in the Chemical Composition of Hybrid Poplar Harvested in December and April after Storage Outside for 26 weeks.[a]

	December Harvest					April Harvest				
	Day Zero	After storage		Absolute % change[b]		Day Zero	After storage		Absolute % change[b]	
Components		Chip Pile	Tree Pile	Chip Pile	Tree Pile		Chip Pile	Tree Pile	Chip Pile	Tree Pile
Extractives[c]	6.6	2.4	3.5	**-4.2**	**-3.1**	4.8	2.5	3.3	3.8	3.8
Ash[c]	1.4	0.7	0.9	**+0.7**	**+0.5**	1.7	1.5	1.0	0.3	**-0.7**
Composition Data on an Extractives-free Basis										
Total Lignin[d]	26.0	27.1	26.8	**+1.1**	**+0.8**	26.3	28.9	27.4	**+2.6**	**+1.1**
Uronic Acids	4.4	4.1	3.4	1.1	1.1	4.4	4.0	3.9	1.1	1.1
Arabinan	0.8	1.1	0.9	**+0.3**	**+0.1**	0.8	0.7	0.7	0.1	0.1
Xylan	14.3	17.4	14.1	**+3.1**	2.0	13.5	15.0	13.5	**+1.5**	**+2.2**
Mannan	2.2	1.6	1.9	**-0.6**	**-0.3**	2.3	2.0	2.3	**-0.3**	0.1
Galactan	1.0	0.7	0.9	**-0.3**	0.1	0.9	0.9	0.8	0.1	0.1
Glucan	44.0	43.4	43.4	2.6	2.6	43.4	42.3	42.8	1.7	1.7
Mass Closure[c]	94.9	97.7	95.6			94.1	96.3	97.1		

The stored material was removed from the center of the piles.
[a]Significant changes at the 95% confidence level are shown in boldface type. Components that showed changes that were not statistically significant are shaded and show the level below which changes would not have been detected.
[b]The changes after storage for 26 weeks are given as absolute percentage changes, for example, the decrease in extractives from 6.6% to 2.4% is a -4.2% change
[c]Contents determined on a whole biomass basis for the -20/+80 mesh fraction
[d]Total lignin and other insoluble materials including condensed proteins, but not ash

A reasonable explanation for the differences in chemical composition determined by the Py-MBMS method observed in the hybrid poplar chip pile is that the pile was frozen throughout the winter, and started to thaw during the spring. It is plausible to assume that after the chip pile thawed, the surface layer was still exposed to very low temperatures which might have inhibited microbial growth and decay of woody tissue. On the other hand, initial respiration of plant cells inside the chip pile after the thawing process might have increased the temperature high enough for microflora to function. This is plausible because it has been shown that cells in aspen (*Populus tremuloides*) board were viable after eight months of storage at 2°C (5).

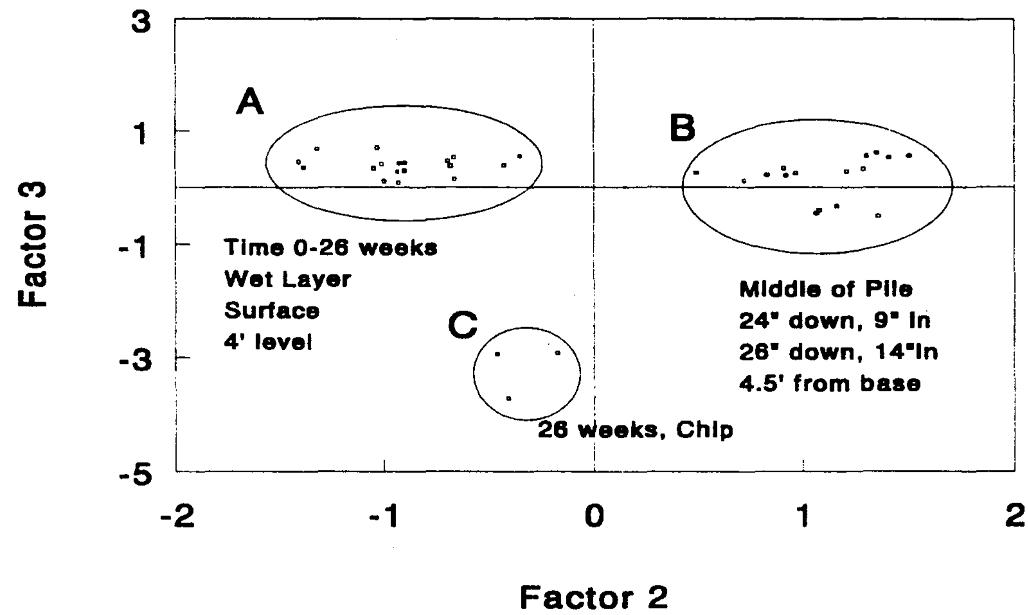

Figure 3. The factor 2 versus factor 3 factor-score plot of the data obtained from the Py-MBMS analysis of the hybrid poplar samples stored unprotected for 26 weeks outside.

Conclusions

The sample set studied included debarked wood chips from three clones of *deltoides x nigra* (DN-17, DN-182, and DN-34) and one clone of *tristis x balsamifera* (NC-5260), harvested at two locations in Wisconsin (Ashland and Mondovi). Within the sample set studied, the NC clones could be identified as being significantly different at an analytical level from all of the DN clones. The composition of the wood chips from the NC-5260 clone was significantly different from that of the DN clones having higher glucan (3%) and extractives (1%) contents, but lower ash (0.2%), lignin (2%) and xylan (1%) contents. The data from Py-MBMS agreed with the composition data that indicates the NC-5260 clone was significantly different from the DN clones, mostly because of differences in carbohydrate and lignin contents.

Overall changes from the stored woody biomass studied were small, particularly for the structural components. The largest change observed occurring across all species studied by the project to date has been loss of extractable materials. It appears that the quality of the feedstocks was not adversely affected by 26 weeks of storage. Among the structural components, consistent change was exhibited by the lignin more than the other components studied. In addition, increases in xylan content were often observed, while changes in glucan content occurred less frequently.

If the variability in hybrid poplar remains within the ranges observed to date it would appear that hybrid poplar could be a consistent and stable feedstock for biofuels production. However, a more definitive answer to the question of how composition variability in hybrid poplar might impact its usefulness as a feedstock for biofuels production cannot be obtained until a much larger number of samples have been analyzed. So far only a small fraction of the viable clones available have been tested, and only a small number of suitable locations sampled. In addition, more samples must be subjected to biochemical and thermochemical conversion before meaningful correlations can be made between compositional variability and biofuels yields.

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NITRATE LOSSES FROM FERTILISED SHORT ROTATION WILLOW - A PRELIMINARY EVALUATION OF TWO YEARS DATA

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Abstract

The contamination of surface and ground waters arising from fertiliser use and livestock husbandry is arousing increasing concern and legislative controls on nitrogen application in vulnerable areas are being applied across the European Union (CEC 1991). The production of wood on agricultural land is increasing as farmers diversify away from food crops. One crop which is attracting significant interest amongst farmers is the production of fuel from intensively planted willow and poplar grown on short rotations, referred to as short rotation forestry (SRF). The management of these crops is substantially less intensive than that employed in traditional agriculture. However, concerns over the potential environmental impact of the large-scale development of SRF have prompted the investigation of its water usage and influence on water quality.

The opportunity was taken to conduct a preliminary investigation of nitrate leaching losses from intensively planted willow through the monitoring of a trial established to examine the fertiliser response of the crop. Two years data are reported in this poster presentation.

Soil pore water samples were collected over two winters using porous ceramic suction samplers installed vertically to a depth of 0.75 m beneath 18 month old stools of *Salix dasyclados* to which 172m^3 ha^{-1} equivalent of sewage sludge was applied in May 1993. Samplers were also installed in unfertilised control plots. Stools were spaced to give stocking densities of 20 000, 10 000 and 6600 ha^{-1}. Sampling commenced in November 1993 and continued at two to four week intervals until the end of May 1994. The process was repeated over the winter of 1994/95.

Nitrate concentrations in soil pore water was significantly higher in the fertilised plots than under the unfertilised controls in both years. However, differences were no longer significant at the end of the sampling period in either year. The pattern of nitrate concentrations found in the soil pore water under each treatment and at each sample date differed between the first and second sampling year. Soil pore water nitrate concentrations differed significantly between plant stocking rates.

This small scale investigation of the leaching of nitrate from SRF has indicated that there is an increased risk of nitrate loss from a fertilised crop of *Salix dasyclados* over an unfertilised crop. However, the highly restricted nature of the study means that considerably more work is required to assess the level of risk.

Introduction

The loss of nitrogen and phosphorus into natural aqueous environments due to intensive agricultural production techniques can lead to a deterioration in both drinking water supplies and aquatic ecosystems through eutrophication processes and the build up of algal populations. Nitrate concentrations in potable water supplies have been steadily increasing and this is likely to continue without the introduction of remedial action to modify land use practices (Smith and Powlesland 1990, DoE 1986, Oakes 1989, Duynisveld *et al*, 1988).

Potentially highly restrictive mandatory controls limiting the timing and rate of nutrient applications to agricultural land are likely to be enforced across the European Union in the future to reduce nitrate leaching from agricultural sources. Currently in the United Kingdom, a Code of good Agricultural Practice for the Protection of Water (MAFF 1991) recommends an annual maximum application of 250 kg N ha^{-1} from organic manures. In the Nitrate Vulnerable Zones, the mandatory level will be set at 210 kg N ha^{-1} yr^{-1} for the first four years, with a possible reduction to 170 kg N ha^{-1} yr^{-1} (CEC 1991).

The use of intensively planted trees as riparian buffer zones to protect water courses from diffuse sources of nitrogen, has been suggested in Europe and North America (Boysen 1992, FRI 1990). Both operational and trial sites have been established using short rotation forestry species to treat wastewater from a variety of sources including domestic wastewater treatment effluent, meat processing effluents and landfill leachate (Perttu 1993, Sims and Ford-Robertson 1992, Hasselgren 1992). Despite this interest, and an increasing acceptance of organic wastes as fertilisers for short rotation energy forestry, there has been relatively little investigation of the loss of applied nutrients through winter leaching. The opportunity was taken to super-impose a small scale, preliminary investigation of nitrate leaching from SRF, on an existing trial which was investigating the the response of the crop to organic and inorganic fertilisers

Materials and method

The investigation of nitrate leaching from short rotation energy forestry was superimposed on a trial established to compare the response of intensively planted willow and poplar to either inorganic fertiliser or sewage sludge, with unfertilised control plots. The main fertiliser trial consisted of three willow and three poplar varieties, one of which, *Salix dasyclados*, was used in this investigation of nitrate leaching. Three spacing treatments of 20 000, 10 000 and 6600 trees per hectare were obtained through intra-row spacings of 1.5, 1.0 and 0.5 m respectively and an inter-row spacing of 1.0 m. Two of the five fertiliser treatment rates, 0 and 172 m^3 ha^{-1} equivalent of sludge, were selected for the monitoring of nitrate concentrations in the soil pore water. Plots comprised of 42 assessment trees with single row guards.

Unrooted cuttings were planted by hand in March 1992. Normal establishment management practices were applied and the crop cutback in January 1993. An application of liquid digested sewage sludge with a dry matter content of 1.65% was made on 5 May 1993. The application rate achieved by the equipment used was 172 m^3 ha^{-1} compared with the original target application of 200 m^3 ha^{-1}. This supplied 111 kg N ha^{-1} of which approximately 94 kg ha^{-1} was be available to the crop in the year of application.

Soil pore water was collected using porous ceramic suction samplers. The use of these samplers permits the regular collection of soil pore water over time (Shepherd 1990) The ceramic cups were constructed specifically for the collection of soil pore water (Soil Water Engineering, Eversholt) following a modified standard design by Earl and Carter (1991). The ceramic section was 55 mm long with an external diameter of 23 mm, inserted into an 85 mm length of PVC pipe which provided a reservoir for the collected sample. Vacuum and sample collection tubes of 2 mm internal diameter were inserted into a neoprene rubber bung which was itself inserted into the reservoir pipe and sealed with epoxy-resin adhesive. The sampling and vacuum tubes could be sealed off using a laboratory ratchet clip.

The porous ceramic samplers were installed vertically to a depth of 0.75 m using a Dutch soil auger in August 1993. The samplers were installed to this depth to ensure that they were below the majority of the root mass and thus sampling soil drainage which was passing out of the rooting zone and into ground or surface water systems. Each sampler was sealed with silica flour HPF5 (Hepworth Minerals and Chemicals, Oakamoor) and de-ionised water to ensure there was adequate contact with the surrounding soil. The soil was reinstated over the sampler in the order removed to maintain the integrity of the soil profile. Four samplers were installed in each plot and each treatment plot replicated three times giving a total of 24 samplers.

To collect samples, a hand held vacuum pump was used to evacuate the samplers by applying a suction of 50-60 kPa. The vacuum was maintained for a minimum of 24 hours by application of the ratchet clip, during which a sample of soil water was drawn into the sampler reservoir. The water was then drawn from the reservoir using a 10 ml disposable syringe which was then sealed. Samples were analysed immediately or temporarily stored by freezing. Nitrate nitrogen analysis was conducted by automated colorimetry.

Samples were collected approximately monthly between November 1993 and June 1994, and between November 1994 and April 1995.

Results

The nitrate losses from the different fertiliser and planting treatments were examined by analysis of variance (ANOVA) and the least significant difference (LSD) between means estimated using Tukey's multiple comparison of means $LSD_{0.05} = SE * Q$ (Little and Hills 1978). The data collected is summarised in Figures 1 and 2. Samples were taken from unfertilised control plots with stool spaced at 0.5 x 1.0 m (NS 0.5 m), from sludged plots at the same spacing (S 0.5m), control plots at 1.0 x 1.0 m spacing (NS 1 m), sludged plots at 1.0 x 1.0 m (S 1 m), control plots with stools at 1.5 x 1.0 m spacing (NS 1.5 m) and sludged plots at 1.5 x 1.0 m spacing (S 1.5 m). Overall the general trend of the data is as might be anticipated, with nitrate concentrations in the soil water initially increasing then decreasing over the winter period, particularly in the first sampling year (Figure 1). The rate of nitrification in soil is very sensitive to soil temperature conditions and essentially is inhibited at soil temperatures below 4° C (Harris 1988).

Sampling Year 1993 - 1994

The average nitrate concentration of the soil drainage water in the first sampling year was 26.7 mg l^{-1} compared with 50.8 mg l^{-1} from the sludged plots. Although there was an increase in the nitrate released from control plots over the first three sample dates, this increase was not significant and only at the final sample date in June were concentrations significantly lower than the rest of the year ($LSD_{0.05}$ = 22.23) (Figure 2a). Soil pore water nitrate concentrations sampled under the fertilised plots were significantly higher than the unsludged controls during the early part of the winter, but there was no significant difference between the control and fertilised plots from mid-February onwards

Tree stocking density also appeared to influence the nitrate release from the fertilised plots. Soil pore water nitrate concentrations were significantly higher under the sludged plots planted at 20 000 and 10 000 stools ha^{-1} than the sludged plots stocked at 6 600 ha^{-1} ($LSD_{0.05}$ = 12.66). Concentrations under sludged and unsludged plots differed significantly at the two higher stocking densities, the pore water from sludged plots having higher concentrations than that from the control plots ($LSD_{0.05}$ = 12.66) Figure 2b).

Sampling Year 1994 - 1995

In the second year after fertiliser application, nitrate concentrations of the soil drainage water under the sludged plots was still significantly higher than the unfertilised controls, 29.57 mg l^{-1} as compared with 22.53 mg l^{-1} ($LSD_{0.05}$ = 3.52) although the mean concentration in the sludged plots over the second sampling period was substantially lower than in the first year. Unlike the previous year, there was no significant difference in the nitrate concentrations in drainage over time (Figure 2c)

Stool spacing again appeared to influence the concentration of nitrate leaching from the plots but the pattern was the reverse of the previous year in that nitrate concentrations in the control plots were significantly lower under the highest stool density, intermediate under those planted at 10 000 ha^{-1} and highest under the plots spaced at 20 000 ha^{-1} ($LSD_{0.05}$ = 8.97) (Figure 2d). There was no significant difference in soil pore water nitrate concentrations as a result of stool spacing under the fertilised plots.

Discussion

A total of 111 kg N ha^{-1} was applied to the fertilised plots of which 94 kg was in the form of NH_4-N. In the years following application an additional 8 kg N ha^{-1} yr^{-1} could be expected to become available through mineralisation of the organic fraction of the sludge. Liquid digested sludge has the highest nitrate production potential of all the forms of sewage sludge (Smith and Woods, 1995). Soil incubation studies have shown that 80-90% of the nitrogen contained in these sludged can ultimately be released as nitrate in the first year after application and hence is available to the crop (Smith and Woods, 1995). This early rapid release of the applied nitrogen from liquid digested sludges may account for the low residual effect of the sludge application as reflected by the much lower nitrate concentrations in the soil pore water sampled from fertilised plots in the second year after sludge application. Crop uptake will also account for the reduction of nitrate concentrations from one year to the next.

Stem nitrogen concentrations of 5.5 g kg^{-1} dry matter have been measured at this site for *Salix dasyclados*. At an average annual yield of 10 oven dry tonnes per hectare, nitrogen exported from the site in harvested stems would be 55 kg ha^{-1}. To prevent site impoverishment by frequent harvesting, nitrogen addition rates ranging from 50 to 150 kg N ha^{-1} yr^{-1} have been suggested (Hansen *et al* 1988, Christerssen 1987, Shoulders and Wittwer 1979). However, the efficiency of recovery of applied nutrients by a crop is highly variable, depending on the fertiliser type, state of crop growth and edaphic conditions such soil moisture, temperature and nutrient status.

An application of 111 kg N ha^{-1} lies within the recommended range for SRF crops mentioned above, and is well below the maximum 250 kg N ha^{-1} yr^{-1} permitted for organic wastes under the Code of Good Agricultural Practise (MAFF 1991). The high proportion of ammoniacal nitrogen in liquid digested sludges means that losses through volatilisation can be as high as 50% during surface application (Smith *et al* 1994). As this is the method most easily employed to apply sludge to short rotation forestry, the efficiency of nitrogen application is potentially low. Despite the relatively low application rate and the potentially high losses, soil pore water nitrate concentrations were elevated in fertilised plots above unfertilised control plots. An estimate of the volume of drainage from the site is required in order to ascertain the proportion of the applied nitrogen which is lost through nitrate leaching and hence assess the level of risk this poses.

Higher nitrate concentrations in the soil pore water sampled from the fertilised plots may not solely have arisen from the applied nutrients. Leave litter degradation may have been accelerated by the availability of nitrogen as an energy source for the soil bacteria. Were this a contributory factor, the nitrate measured in the soil drainage water could originate from degrading leaf litter as well as from the applied fertiliser.

It could have been anticipated that a high density of planting would lead to lower concentrations of nitrate in the soil drainage water for two reasons. A denser rooting network is likely to develop at high plant stocking rates and competition for applied nutrients may arise more quickly as the soil volume is more fully exploited. The difference in the soil water nitrate concentrations between the control and the fertilised plots at different stocking densities in the second sampling year, may be indicative that competition for nitrogen is already taking place. The nitrate concentrations under the control plots with the highest stocking densities were significantly lower than the fertilised plots and the control plots planted at 10 000 and 6600 stools ha^{-1}. It cannot be ascertained from the data why there should be higher nitrate concentrations in soil drainage water under the more densely planted and fertilised plots in the first sampling year after sludge application. In neither year is there any significant difference in the nitrate measured under the control and fertilised plots planted at 6600 stools per hectare. Two years data are not sufficient to establish whether there is an influence of crop planting density on soil drainage water nitrate concentrations.

The site was not particularly suited to the examination of nutrient leaching. The soil is very stony in places and consequently, short circuiting of drainage water down interfaces between samplers and stones, could have occurred. This may have been avoided if the method employed had been regular soil sampling and subsequent centrifuging to obtain soil pore water. However, the frequent sampling of small plots by this technique may have influenced the drainage pattern. In addition the winter water table at this site can be high.

In this event, the collected sample may have flowed laterally through the soil, rather than being drainage water which has percolated down through the soil from the surface. Were this to happen, the nitrate contained in the sample may have originated from another location and not from the trial plots.

This preliminary investigation of nitrate losses from SRF has indicated that there is an increased risk from fertilised plots. However, the extremely limited nature of the investigation means that considerably more work is required to understand the level of risk this represents.

Conclusions

There is an increased risk of nitrate leaching from *Salix dasyclados* to which 111 kg N ha^{-1} has been applied over unfertilised control plots, in both the winter following a spring application of fertiliser and in the year following.

The planting density of the stools appears to have a significant effect on the nitrate release pattern. However, this influence was not consistent over the two years of sampling. Further monitoring would be required to establish whether stool spacing has any longer term effect on the nitrate concentrations of soil drainage water.

Further work is required to explore in greater detail, the potential for winter nitrate leaching from fertilised short rotation forestry crops. A trial established specifically for this purpose would better address these issues.

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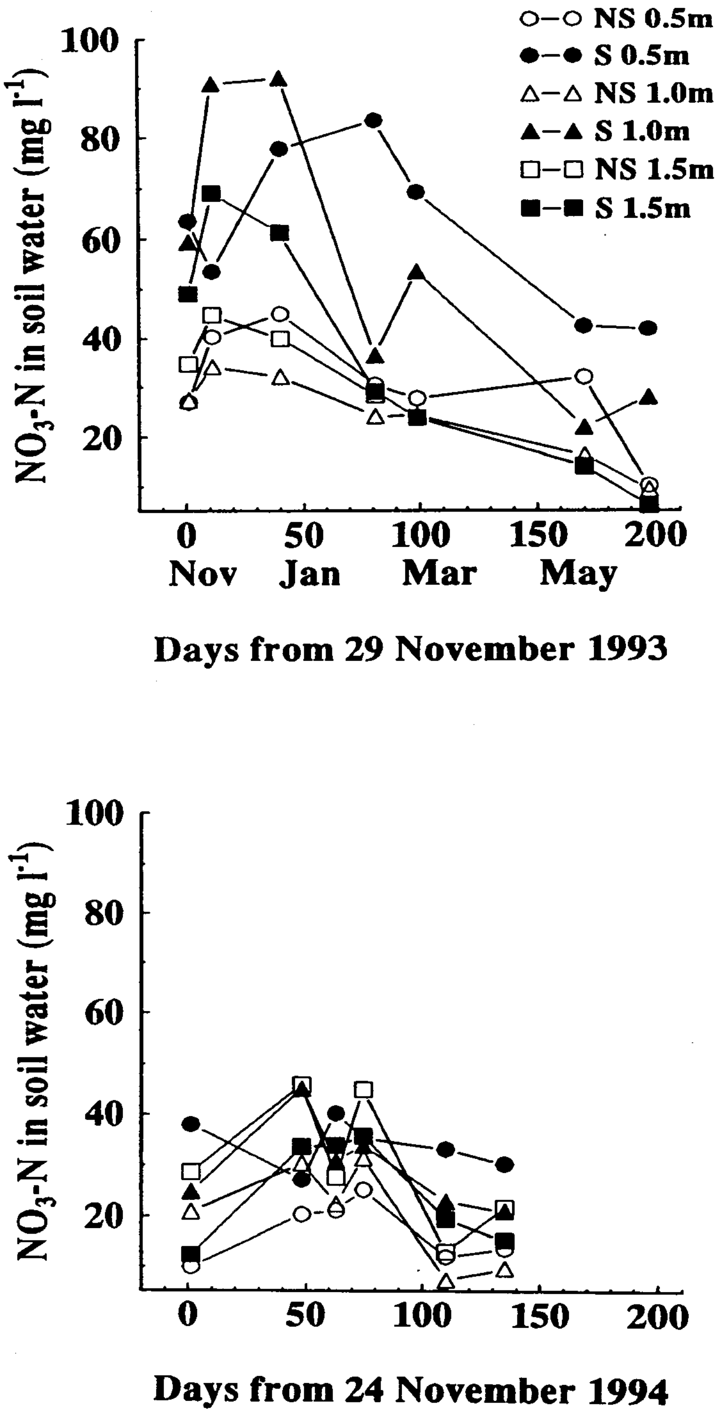

Figure 1 Concentrations of NO_3-N in soil pore water sampled over two winters (see text for key)

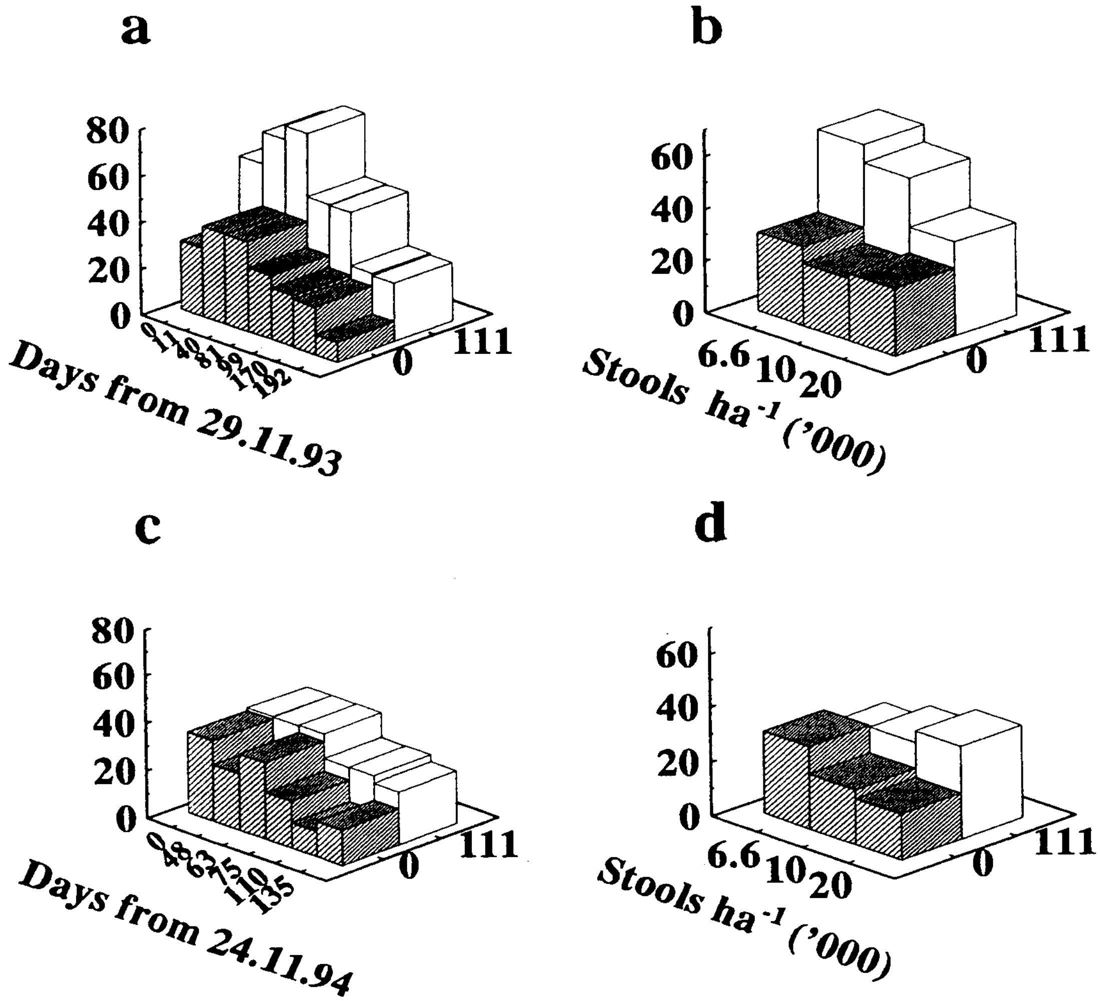

Figure 2 Influence of stool density, nitrogen application rate and sampling date on NO_3-N concentrations in soil pore water in season 1993-94 (a & b), and season 1994-95 (c & d)

PRODUCTIVITY OF POPLAR GROWN ON SHORT ROTATION IN SPAIN: INFLUENCE OF THE ROTATION AGE AND PLANT DENSITY

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Abstract

The objective of this work is to evaluate the growth potential and biomass productivity of poplar on short rotation for different growth cycles and plant densities in southern Europe.

Five poplar clones have been tested: Unal, Beaupre, Hunnegen, Boelare and Raspalje, all are hybrid clones P. trichocarpa x P. deltoides. For each clone, plant densities of 10000, 5000, 2500 and 1666 trees/ha have been assayed, for growth cycles of 2, 3, 4 and 5 years.

The experimentation was initiated in 1986 at Castilla y León, region in Spain. The situation of the plantation is 41°36′N and 2°30′E (Greenwich meridiane), at an altitude of 1010 m above the sea level. The average rain precipitation is of about 550 mm/year and the average temperature, 10.5°C.

The parameters evaluated for each plant after harvesting have been: total dry weight of the aerial part and dry weight, height and basal diameter of the stems.

The highest biomass productivity, next to 20 t/ha.year, was achieved for Raspalje clone, utilizing 10000 trees/ha plantation density and growth cycle of 5 years. Under these conditions the average diameter of the stems was 9.5 cm and the average height of the trees was 7.9 m.

Introduction

In order to avoid the agricultural surpluses, the new Common Agricultural Policy of the European Union has determined the set aside of about 15% of agricultural land surface for food production.

Non food crops and in particular energy crops offer an alternative for utilization of set aside lands as well as for marginal lands.

In Spain this Policy will affect to more than 1 million hectares of agricultural land.

In this context, the poplar because its fast growth and capacity of sprouting is one of the studied crops in Spain to be used for energy purposes.

Presently, poplar is traditionally grown in fresh and irrigated areas of the northern-central part of the country, on a surface of about 100000 ha that produce more than 500000 m^3 of wood per year.

In the past decades, poplar wood was used as a packaging material but now it has been substituted by plastics and other synthetic products, and therefore the above mentioned wood production could be also potentially used for energy production.

In this context, the group presenting this work is studying from ten years ago the implantation possibilities of poplar in Spain as energy crop.

A part of the results obtained related to the influence of the rotation age and plant density on the productivity of five poplar clones are here presented.

Objetives

The main objetive of the work is to make a comparative study of the influence of rotation age (2, 3, 4 and 5 years) and plant density (10000, 5000, 2500 and 1666 trees/ha) on the productivity of five poplar clones.

Materials y Methods

1. Experimental parcel location.

The experimental parcel with a total area of 1,5 ha, is located at CIEMAT-CEDER (Soria-Spain) in northern central Spain, at an altitude of 1010 m above the sealevel. The average annual temperature is 10,5°C, and the average rain precipitation of about 550 mm. The climate conditions are continental extreme.

The soil has a sandy texture: sand (70-85%), slime (0-15%), clay (10-20%). It is light, with good drainage and scarce productivity for agriculture.

2. Experimental design.

The experimental plantations were initiated in 1986, being utilized the next poplar clones: Unal, Beaupré, Hunnegen, Boelare and Raspalje. All are hybrid P. trichocarpa x P. deltoides.

In the parcels, the separation between lines was 2 m and the spacing of trees was of 0.5, 1, 2 and 3 m (10000, 5000, 2500 and 1666 trees/ha). Three plots, each with eight trees randomly located in the global experimental parcel, for each clone and rotation age have been grown. Surrounding the parcels three ranges of trees, N-S direction and 4 ranges E-W, as well as three more ranges between the spacings were planted in order to avoid the border effect.

3. Site preparation.

In the first year, the soil was prepared for planting as follows:
- Application of pig manure fertilizer (50 t/ha) during the fail period prior to planting. It was followed by soil ploughing.
- Braking operation.
- Addition of NPK (9-18-27) (600 kg/ha) with braking prior and after the application.

The trees plantation was manually made, utilizing unrooted 25 cm long poplar cuttings. This operation was followed by a dressing brake to remove the weed.

The parcel was then irrigated from July to September (five irrigations, about 400 m3/ha each)

In the following year only removing the weed by dressing brake and irrigation as described were made. No irrigation was made in the succesive years.

4. Productivity evaluation.

After growth cycles of 2, 3, 4 and 5 years, the trees were severed at groundline, and the following parameters were measured for each plant:
- Total dry weight of the aerial biomass (branches and stem).
- Weight, height and basal diameter of the stem.

5. Statistical procedures.

The F-Fisher-Snedecor method was used to identify significant differences between mean values.

Results and Discussion

In the tables 1, 2, 3, and 4, mean values of dry aerial biomass (total, stem and proportion of the stem to the total weight), height and basal diameter of the stem, for the different clones and rotation age studied, are shown.

Table 1: Average Characteristics of the Poplar Clones at a Planting Density of 10000 trees/ha. Results of Biomass Production are expressed in kg of Dry Matter per Tree.

Clone	Rotation age (years)	Biomass			Height (m)	Diameter (cm)
		Total (T)	Stem (S)	S/T		
Unal	2	0.93	0.56	0.60	3.4	3.9
	3	2.51	1.74	0.69	5.1	5.7
	4	2.75	1.68	0.61	4.8	6.1
	5	7.74	5.81	0.75	7.9	8.7
Beaupré	2	0.86	0.51	0.59	3.2	4.0
	3	1.57	1.01	0.64	3.9	4.9
	4	3.04	2.04	0.67	5.1	6.5
	5	6.77	5.36	0.79	7.7	8.4
Hunnegen	2	0.97	0.57	0.59	2.8	4.1
	3	1.80	1.24	0.69	4.3	5.2
	4	2.22	1.58	0.71	4.4	6.0
	5	7.04	5.58	0.79	7.4	8.1
Boelare	2	0.75	0.40	0.53	2.9	3.6
	3	2.45	1.45	0.59	4.2	5.7
	4	3.58	2.13	0.59	4.7	7.1
	5	8.30	6.42	0.77	7.8	9.4
Raspalje	2	1.25	0.70	0.56	3.4	4.6
	3	2.67	1.76	0.66	4.9	5.6
	4	2.87	1.87	0.65	5.0	6.4
	5	9.91	7.92	0.80	7.9	9.5

Table 2: Average Characteristics of the Poplar Clones at a Planting Density of 5000 trees/ha. Results of Biomass Production are expressed in kg of Dry Matter per Tree.

Clone	Rotation age (years)	Biomass			Height (m)	Diameter (cm)
		Total (T)	Stem (S)	S/T		
Unal	2	1.70	0.92	0.54	3.7	5.0
	3	3.59	2.16	0.60	5.0	6.0
	4	4.68	2.90	0.62	5.4	7.2
	5	8.63	6.89	0.80	8.3	8.9
Beaupré	2	1.35	0.74	0.55	3.4	4.6
	3	4.03	2.60	0.65	5.0	6.3
	4	4.20	2.61	0.62	5.3	7.4
	5	8.08	6.11	0.76	8.0	8.5
Hunnegen	2	1.61	0.95	0.59	3.4	5.1
	3	3.88	2.48	0.64	5.5	6.7
	4	4.14	2.59	0.63	4.8	6.9
	5	9.43	7.45	0.79	8.3	9.4
Boelare	2	1.72	0.77	0.45	3.2	4.8
	3	4.93	3.13	0.63	5.2	7.2
	4	5.20	2.73	0.53	5.1	7.8
	5	9.81	7.32	0.75	8.2	9.6
Raspalje	2	1.72	0.94	0.55	3.6	5.0
	3	5.30	3.29	0.62	6.2	7.6
	4	5.51	3.31	0.60	5.5	8.1
	5	10.74	8.23	0.77	8.5	10.2

Table 3: Average Characteristics of the Poplar Clones at a Planting Density of 2500 trees/ha. Results of Biomass Production are expressed in kg of Dry Matter per Tree.

Clone	Rotation age (years)	Biomass			Height (m)	Diameter (cm)
		Total (T)	Stem (S)	S/T		
Unal	2	2.03	1.05	0.52	3.6	5.5
	3	9.37	5.46	0.58	7.0	9.3
	4	9.28	5.80	0.63	6.3	9.2
	5	12.19	6.84	0.56	6.0	11.2
Beaupré	2	1.23	0.69	0.56	3.0	4.6
	3	6.72	3.73	0.56	5.8	8.8
	4	6.91	3.55	0.51	6.0	8.8
	5	13.10	7.61	0.58	6.7	11.7
Hunnegen	2	1.21	0.67	0.55	2.7	4.6
	3	7.38	4.73	0.64	5.6	8.7
	4	7.32	4.29	0.59	6.1	9.0
	5	14.00	8.43	0.60	6.6	11.9
Boelare	2	1.26	0.59	0.47	2.8	4.6
	3	6.57	3.41	0.52	5.5	8.3
	4	6.97	3.60	0.52	5.1	8.9
	5	16.88	10.45	0.62	8.1	12.4
Raspalje	2	1.78	0.87	0.49	3.2	5.2
	3	7.85	4.43	0.56	6.3	8.9
	4	8.75	5.06	0.58	6.2	9.3
	5	17.74	12.38	0.70	9.1	12.5

Table 4: Average Characteristics of the Poplar Clones at a Planting Density of 1666 trees/ha. Results of Biomass Production are expressed in kg of Dry Matter per Tree.

Clone	Rotation age (years)	Biomass			Height	Diameter
		Total (T)	Stem (S)	S/T	(m)	(cm)
Unal	2	3.20	1.39	0.43	3.9	6.6
	3	9.74	5.05	0.52	6.3	9.8
	4	12.21	7.17	0.59	6.7	10.6
	5	19.52	14.06	0.72	9.8	13.1
Beaupré	2	2.56	1.31	0.51	3.6	5.9
	3	9.37	5.48	0.58	5.9	8.9
	4	10.80	6.68	0.62	6.7	10.2
	5	17.05	12.14	0.71	8.8	12.4
Hunnegen	2	2.34	1.19	0.51	3.3	6.0
	3	9.72	5.59	0.58	6.2	9.5
	4	11.82	6.72	0.57	6.4	10.4
	5	16.27	11.73	0.72	8.8	12.1
Boelare	2	2.76	1.04	0.38	3.2	6.0
	3	8.48	3.79	0.45	5.5	9.2
	4	11.91	5.98	0.50	6.5	10.4
	5	17.23	8.89	0.52	6.6	13.4
Raspalje	2	3.07	1.44	0.47	3,8	6.4
	3	10.56	5.99	0.57	6.6	9.8
	4	15.15	8.03	0.57	7.0	11.1
	5	17.31	9.71	0.56	7,5	12.5

As can be observed in tables 1-4, the best results in terms of biomass production per tree were achieved in all cases for a growth cicle of five years and at the lowest plant density.

A strong correlation between the lenght and the diameter of the stems can be observed in all cases, as well as between both parameters and the total weight of the plants for a determinate density of plantation. As bigger are the lenght and diameter of the stem, bigger is the total weight of the plant. Bigger stem diameter determines a higher tree. These results are similar to those described by other authors (Chauhan et al. 1992).

In general, as can be observed in tables 1-4, for a particular clone the proportion of the stem to the total weight of the tree (index S/T) increases with the age of trees and in particular with the density of plantation. This effect is more remarked in higher density parcels. On the other hand, the ratio diameter/height of the stem as calculated from data of tables 1-4, decrease for each clone as increases the age of the tree and the plant density.

All the described facts could be explained because of the competitiviness among the individual trees for the physical space in the plantation as well as for the sun irradiation, this competitiviness should be stronger for the higher planting densities and is more remarked along sucessive years during the growth cycle of the trees.

Therefore, higher densities of plantation and longer growth cycles result in trees with weaker stems but higher S/T indexes which are in principle favourables characteristics for harvesting and ulterior processing of the biomass for energy.

As observed in the cited tables, most significant encrease of biomass production and trees growth was obtained between the 4th and 5th year from the plantation in all cases. The gains of biomass during this period were mainly related to the main stem development being relatively low the biomass production from branches fraction. It is also to mention the very scarce biomass production in the period between 3th and 4th year from plantation which can not be well explained as a result of the available data.

On the contrary to that achieved for individual trees (see table 5), highest biomass productivities per hectare have been obtained for the highest plantation densities in all cases.

Table 5: Biomass Productivity for Different Poplar Clones, Rotation Age, and Plant Density.

Clone	Rotation age (years)	Biomass (t d.b./ha.year)			
		10000 trees/ha	5000 trees/ha	2500 trees/ha	1666 trees/ha
Unal	2	4.6	4.2	2.5	2.6
	3	8.3	5.9	7.8	5.4
	4	6.9	5.8	5.8	5.1
	5	15.5	8.6	6.1	6.5
Beaupré	2	4.3	3.4	1.5	2.1
	3	5.2	6.7	5.6	5.2
	4	7.6	5.2	4.3	4.5
	5	13.5	8.1	6.5	5.7
Hunnegen	2	4.8	4.0	1.5	1.9
	3	6.0	6.5	6.1	5.4
	4	5.5	5.2	4.6	4.9
	5	14.1	9.4	7.0	5.4
Boelare	2	3.7	4.3	1.6	2.3
	3	8.2	8.2	5.5	4.7
	4	8.9	6.5	4.4	4.9
	5	16.6	9.8	8.4	5.7
Raspalje	2	6.2	4.3	2.2	2.5
	3	8.9	8.8	6.5	5.8
	4	7.2	6.9	5.5	6.3
	5	9.8	10.7	8.8	5.7

Best productivity results were achieved with the clone Raspalje grown in a five years rotation period and at a density of 10000 trees/ha. Under these conditions, and as reflected in the mentioned table, dry biomass productivity has been (19.80) t/ha on a year average. These results are, in general, higher values than those cited in literature but have already been obtained by some other authors (Strauss et al. 1987, Makeschin 1989, Buitelaar 1994).

The results achieved show the interest of poplar grown in short rotation and high densities as energy crop in fresh areas of Southern Europe, even at altitudes of 1000 m above the sea level. The results also reflect the good adaptation of this spice to poor soils as that employed in this work, and therefore the possibility to be grown in poor agricultural or marginal lands.

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HIGHER HEATING VALUES FOR PELLETS MADE FROM SHORT ROTATION BIOMASS OF HARDWOOD SPECIES

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Abstract

The use of pelletized woody biomass for fuel has increased substantially in recent years. The purpose of this study was to determine the higher heating values and ash content on four-year-old short-rotation trees: autumn olive, black alder, cottonwood and sycamore. These plantations were established on marginal agricultural land that was not suitable for food production in Midwestern United States. The effects of tree species, site, and regeneration technique on the fuel value were determined. For comparison purposes, the heat content of three commercial lumber species was also obtained. Test results indicated that the planting sites (bottomland versus upperland) and regeneration method (seedling-grown versus coppice-grown) factors did not affect the higher heating values of all pelletized specimens. The heat values averaged 4728 calories per oven-dry gram, which is greater than the 4580 cal/gram of three commercial hardwoods. The main factor species, as well as the interactions of species by site, species by regeneration, and site by regeneration, were significant factors in determining heat value. Black alder had the highest heat value, followed by autumn olive, cottonwood, and sycamore. Furthermore, a preliminary experiment indicates that alcohol, a liquid fuel, can also be made from the short rotation hardwoods in the laboratory scale. It is likely a pelletized coal product using lignin waste derived from the wood hydrolysis stage of the ethyl alcohol conversion process can also be made in the future.

Introduction

The objective of this study was to determine the effects of slivicultural practices, such as tree species, plant site, and regeneration technique on the energy value and ash content of short-rotation deciduous trees. They were planted on marginal agricultural land that was not suitable for food production in the Midwest.

Today, petroleum and coal still provide our major supply of fuel, but the distinct advantages of its price and supply relative to other fuels are diminishing. Pelletized wood biomass is a feasible alternative to petroleum due to advances in technology that have enabled industry to efficiently utilize an abundant and cheap resource such as pelletized wood for uses and products currently supplied by oil. It is commonly known that pelletized denser woods are better forms of fuel because they burn slower and contain more heat energy per unit volume of material than do natural woods (Hasse et al, 1993). The uses of furnaces and stoves fueled by compressed pellet has increased dramatically in industry and public buildings in recent years. Wood produced under short-rotation systems can provide a continuous supply of high quality feedstock for energy (Chow et al, 1983). Short-rotation wood production systems involve fast growing deciduous species planted at close spacings and harvested over short rotations.

In order to determine the optimal end use of pelletized wood biomass, the physical properties of wood must be studied. Differences in properties will ultimately lead to different conversion efficiencies of energy. Some properties that can dictate functional use include ash or mineral content and heat of wood combustion.

The deciduous or hardwood species included in this study were autumn olive (*Elaeagnus umbellata* Thumb.), black alder (*Alnus glutinosa* L.), eastern cottonwood (*Populus deltoides* Bartr.), and sycamore (*Platanus occidentalis* L.). Trees were grown on upland and bottomland sites originating from seedling and coppice regeneration techniques. Understanding the effects of species, site, and regeneration technique on heat value and ash content properties can then lead to efficient energy utilization of specific trees grown under different silvicultural conditions. Coppicing is essential to the success of short-rotation forestry practice because it eliminates planting expense for three to four rotations while providing yields of 20 to 100 percent above seedling yields. To date, little information is available in this area.

Materials and Methods

Material and Sample Preparation

Tree specimens were grown on upland and bottomland sites located in southern Illinois at the University of Illinois, Dixon Springs Agricultural Center. Whole, four-year-old trees originating from seedlings were harvested, chipped, dried, and stored. Four years later the coppice trees were harvested. Sample trees were randomly selected for use as either material for moisture content and density samples or whole tree experimental material

(Table 1). The tree stems used for experimental material from both seedling and coppice sources were chipped, air dried, and hammermilled. The coarse material was then ground in a Wiley mill to pass a 40 (425 um) mesh screen for ash analysis, and to pass a 60 (250 um) mesh screen for heat content analysis. Both ground wood materials were then stored in separate glass jars during the testing period.

Table 1.

Average Moisture Content (Percent-Dry Basis) and Density (gram/cm³) of Material for each Species by Site Combination

SPECIES	SITE	[1]	MOISTURE CONTENT (%)	DENSITY (g/cm³)
autumn olive	upland	S	8.1	0.70
		C	9.2	0.71
	bottom	S	-- [2]	--
		C	8.2	0.69
black alder	upland	S	7.0	0.48
		C	7.0	0.47
	bottom	S	8.2	0.47
		C	7.9	0.45
cottonwood	upland	S	9.0	0.41
		C	10.0	0.38
	bottom	S	9.0	0.39
		C	--	--
sycamore	upland	S	9.4	0.54
		C	9.0	0.54
	bottom	S	8.9	0.62
		C	10.2	0.50

[1] S -- seedling
C -- coppice

[2] Trees were not available

Design and Analysis (SAS, 1992)

A randomized compete block (RCB) design was used in the factorial analysis to determine the effects of the treatment combinations of species, site, and regeneration on each dependent variable. The dependent variables were: ash content and heat of combustion.

Treatment levels for species were: A_1 = autumn olive (*Elaeagnus umbellata* Thumb.); A_2 = black alder (*Alnus glutinosa* L.); A_3 = eastern cottonwood (*Populus deltoides* Bartr.); A_4 = sycamore (*Platanus occidentalis* L.). Treatment levels for site were:

B_1 = upland; B_2 = bottomland. Treatment levels for regeneration were: C_1 = seedling; C_2 = coppice.

The overall analysis of the RCB was a 4 x 2 x 2 factorial design for each dependent variable. The following 3-way ANOVA model with interaction was used for explaining sources of variation:

$$Y_{ijkl} = U + A_i + B_j + C_k + AB_{ij} + AC_{ik} + BC_{jk} + ABC_{ijk} + E_{ijkl}$$

where, Y_{ijkl} = any observed value for physical properties; U = overall mean; A_i = species effect; B_j = site effect; C_k = regeneration effect; AB_{ij} = species by site interaction; AC_{ik} = species by regeneration interaction; BC_{jk} = site by regeneration interaction; ABC_{ijk} = species by site by regeneration interaction; E_{ijkl} = experimental error and i = 1,----4 levels of A; j = 1,2 levels of B; k = 1,2, levels of C; l = 1,----6 replications for all properties.

Not all the combinations of independent variable were available for this study. Table 1 shows the missing combinations. Because of this, two supplemental analyses had to be included for an accurate interpretation. The first supplemental analysis consisted of a 4 x 2 ANOVA model with interaction. This model can be written as:

$$Y_{ikl} = U + A_i + C_k + AC_{ik} + E_{ikl}$$

where, i = 1,----4 levels of A (species), and k = 1,2 levels of C (regeneration).

The second supplemental analysis was a 2 x 2 x 2 ANOVA model with interaction. This model can be written as:

$$Y_{ijkl} = U + A_i + B_j + C_k + AB_{ij} + AC_{ik} + BC_{jk} + ABC_{ijk} + E_{ijkl}$$

Test Procedures

All experimental procedures followed the method described in the standards of American Society of Testing and Materials (ASTM). Six tests were made for each replicate and each combination of independent variables. For comparison purposes, three species of commercial lumber were also collected and prepared, following the same preparation methods as used for the juvenile wood. The ASTM D2015 was used for determining the higher heat content value and the ASTM D1102 was used for the ash analysis (ASTM, 1993).

Higher Heat Value of Wood Pellet by the Adiabatic Bomb Calorimeter (ASTM D2015)

A one-gram of 60 mesh sample was weighed and made into a pellet by using a pellet press. The pellet was placed on the holder of the oxygen bomb head. Next, the oxygen bomb was closed tightly and charged with oxygen to 30 atmosphere. The bomb was then placed into the calorimeter. The fuse was ignited and held for nine minutes.
A calculation of the gross heat value was made by the following formula:

$$Hg = (Tw - \ell 1 - \ell 2 - \ell 3)/m$$

where, Hg = higher or gross heat of combustion (calories per gram); T = corrected temperature rise (C°); m = mass of pellet in grams; w = standard value for calorimeter which decided by benzoic acid pellet; $\ell 1$ = correction for the heat of formation of HNO_3; $\ell 2$ = correction for the heat of formation of H_2SO_4; $\ell 3$ = correction in calories for heat of combustion of fuse wire.

Ash in Wood (ASTM D1102)

The wood specimen was put into a crucible with known weight (2 grams), then the crucible was placed in the muffle furnace at 575 ± 25°C for six to eight hours. After cooling to room temperature in a desiccator, the material was weighed accurately. the heating process was repeated for 30-minute periods until the weight after cooling was constant to within 0.2 mg. A calculation of the ash content was made.

Results and Discussion

Because of the missing blocks of data, presenting and comparing means for species, sites, and regenerations can be biased and misleading. Non-biased means for species and regeneration were compared for upland sites, where all combinations of independent variables exist. Means for site, however, if stated, would be biased values. Relative values were projected by using the upland means of species and regeneration and adjusting them if the effect of bottomland was significantly higher or lower than the effect of upland.

Higher or Gross Heat Value (HHV)

The heat value (or calorific value) of a combustible material is the negative of the standard heat of combustion, usually expressed per unit mass of the material. the higher heat value (or gross heating value) is heat of combustion with liquid water as a combustion product. The net heat value (or lower heating value) is the value based on water vapor as a product.

The heating value in this study was not affected by moisture content of the wood, for it was calculated on the dry basis. Any water evaporating during combustion was condensed and its latent heat was recovered; in other words, the heating value in this study was higher heat value or gross heating value.

The heats of combustion of the fourteen materials averaged 4728 calories per oven-dry gram, which is greater than the 4580 cal/gram of mature hardwoods. The HHV's, listed in Table 2, varied from 4638 to 4813 cal/gram. Larger values may result from higher lignin and extractive components supplied by bark and sapwood.

Table 2.

Average Higher Heat of Combustion (HHV) and Ash Content of each Combination of Species, Site, and Regeneration[1]

Species	Site	Regeneration	Heat of Higher Combustion (cal/g)	Ash Content (%)
autumn olive	upland	seedling	4790	0.915
		coppice	4789	0.927
	bottom	seedling	--	--
		coppice	4724	0.732
black alder	upland	seedling	4773	0.991
		coppice	4813	0.914
	bottom	seedling	4768	0.971
		coppice	4784	1.017
		lumber	4623	0.37
cottonwood	upland	seedling	4740	1.429
		coppice	4681	1.163
	bottom	seedling	4694	1.154
		coppice	--	--
		lumber	4472	1.07
sycamore	upland	seedling	4638	1.042
		coppice	4649	1.032
	bottom	seedling	4699	0.992
		coppice	4647	1.128
		lumber	4640	0.25
Overall Mean (no lumber value)			4728	1.029

[1] Based on six replicates

Table 3 shows that the main variable species, as well as the interactions species by site, species by regeneration, and site by regeneration, were significant factors in determining heat of combustion. Site and regeneration were both insignificant.

Table 3.

Summary of Significant Factors of each Property[1]

PROPERTY	FACTORS						
	A[2]	B	C	AB[3]	AC	BC	ABC
Ash Content	S	S	N	N[4]	S	S	N
Higher Heat of Combustion (HHV)	S	N	N	S	S	S	N

[1] S = significant at alpha = .05, N = not significant
[2] A = species, B = site, C = regeneration
[3] Combinations of letters represent factor interactions
[4] Significant in the full model (4 species), but not significant in supplemental analysis 2 (2 species)

Table 4 shows that all species means were significantly different in the Tukey test. Wood material of black alder had the highest HHV, followed by autumn olive, cottonwood, and then sycamore. Respective upland means were 4793, 4790, 4710, and 4643 calories per gram. The coefficient of variation of heat of combustion was 0.35 percent.

Table 4.

Summary of Tukey's Studentized Range Test of Species for each Property

PROPERTY	SPECIES			
Ash Content	CW	SY	BA	AO
Higher Heat of Combustion (HHV)	BA	AO	CW	SY

1 Significance level = .05
2 Left to right are highest to lowest species means
3 AO = autumn olive, BA = black alder, CW = cottonwood, SY = sycamore

Ash Content

Ash is the residue that remains after complete combustion of wood. Calcium, potassium, and magnesium account for about 70 percent of total ash with varying amounts of silicon, sodium, iron, and aluminum combining for the remainder. Although fertilizer is a possible use for ash, ash is mainly a nuisance waste product that must be removed periodically. Accumulation of ash reduces furnace efficiency.

Values of ash or mineral content for available combinations of independent variables are shown in Table 2. Ash contents ranged from 0.73 to 1.43 and averaged 1.03 percent of oven-dry wood. The magnitude of values were approximately double the known ash contents of mature hardwoods, which suggests a trend of decreasing ash content with increasing age. Evidently, juvenile hardwoods must require larger quantities of mineral substances for growth and development. The coefficient of variation of all tests averaged 3.59 percent.

Summary and Conclusions

1. The measurements of the physical properties of the test samples indicated that there was no significant variation in heat content and ash content of the six replicates. All of the independent variables and their interactions were important factors in explaining variation of the selected physical properties of wood. The main variable, species, the site by regeneration, and the species by regeneration interaction were the most frequent significant factors of the two properties studied.

2. When comparing the results of four-year-old material from this study with previous results of mature hardwoods, four-year-old wood contained higher ash content and heat of combustion. These properties seem to be a function of age. As age increases, the juvenile wood component is changed or reduced along with the ash and heat contents.

3. When comparing species, autumn olive could be a feasible source of fuel because of its high heat and low ash contents. Black alder's high heat of combustion and low ash content make it an ideal fuel source. Although juvenile cottonwood has a low heat of combustion relative to the other juvenile species, it actually has a high heat when compared with three mature hardwoods.

4. The variable, regeneration method, was not significant in affecting ash content or heat of combustion properties.

5. The property with the lower coefficient of variation or highest precision was heat of combustion (0.35 percent). Ash content had a higher coefficient of variation of 3.59 percent.

6. Results from this study showed that these four juvenile hardwood species can produce high biomass yields of energy when grown under intensive care in southern Illinois marginal land sites. The better species of these tested woods seem to be black alder and

autumn olive, which could also serve as raw material for a pelletized fuel for energy generation. However, further economic and energy efficiency analyses are needed before judging the feasibility of these short-rotation juvenile hardwood species.

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EVALUATION OF SWITCHGRASS AS A SUSTAINABLE BIOENERGY CROP IN TEXAS

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Abstract

Switchgrass (Panicum virgatum L.) has been selected as a model herbaceous biomass feedstock by the U.S. Department of Energy. Texas A&M University/The Texas Agricultural Experiment Station was selected as one of three Regional Switchgrass Cultivar and Management Testing Centers in 1992 by Oak Ridge National Laboratory. Research in Texas encompasses (1) evaluating switchgrass germplasm at six locations, (2) determining defoliation, fertility, and row spacing response of switchgrass, (3) selecting for differential crown node elevation and reduced seed dormancy in Alamo switchgrass, (4) basic studies on switchgrass morphology, and (5) response of switchgrass to land application of municipal and agricultural wastes. Research locations span a north-south range of 725 km. We report on results from Objective 1 in this paper. Alamo switchgrass has been one of the best performing cultivars at all locations with yields ranging from 8 to 20 Mg of dry biomass ha^{-1}. Increased production of Alamo in response to N fertilizer was quadratic at Stephenville and linear at Beeville to the highest N rate used of 200 kg ha^{-1}. There was a small response to 20 kg ha^{-1} of P_2O_5 in 1992 at Stephenville, but no response in later years or at Beeville. Row spacing has not had a consistent effect on switchgrass yield. Harvest frequency studies have shown that total seasonal yields are decreased as harvest frequency increases. We have made progress in selecting populations for enhanced and reduced crown node (subcoleoptile internode) elevation and in reduced post harvest seed dormancy.

Introduction

The U.S. Department of Energy, through the Biofuels Feedstock Development Program at Oak Ridge National Laboratory, initiated a biomass technology research program in 1992 (McLaughlin, 1993). The biofuels program includes investigations into biomass production, economics, and environmental impacts at five primary locations in the southcentral and southeastern U.S. The Texas A&M University/Texas Agricultural Experiment Station was chosen as one of three Regional Cultivar and Management Testing Centers.

Switchgrass was selected for development as a bioenergy feedstock because of its high yield potential, adaptation to marginal sites, and tolerance to water and nutrient limitations. It is a warm-season perennial grass native to much of North America and is a major component of the tall grass prairie. Switchgrass has been researched extensively as a forage crop particularly in the midwestern and northeastern U.S.; however, little research has been done on switchgrass as a biomass or forage crop in Texas. Therefore, the objective of our research was to answer three applied questions: (1) what switchgrass cultivars or germplasm are widely adapted in Texas?, (2) what are the fertilizer requirements of switchgrass?, and (3) what type of harvest management (frequent or infrequent) is necessary for switchgrass in Texas?

Materials and Methods

Experiment 1: Cultivar and Germplasm Evaluations: Cultivar and germplasm evaluation trials were established at Beeville, College Station, Dallas, Knox City, Stephenville, and Temple in 1992 (Fig. 1). Knox City is the northernmost location (242 km north of Abilene) and Beeville is the southernmost location (145 km south of San Antonio) (Fig. 1). Eight switchgrasses (Alamo, Kanlow, Cave-in-Rock, Caddo, PMT-279, PMT-785, NCSU-1, and NCSU-2) were planted into 3- by 6-m plots in a randomized complete block design. Plots were harvested once per year in the fall or twice per year in June and October. Harvest systems (1-cut or 2-cut) were whole plots and switchgrass cultivars and germplasm were subplots. There were two replicates of each system-cultivar treatment combination. Because of poor establishment in some plots, the two-cut system was dropped at Knox City and Stephenville. The Stephenville site was replanted in 1993.

Plots were fertilized with 67 kg N ha^{-1} in 1993 and 134 kg N ha^{-1} in 1994. At each harvest, biomass was clipped to a 15-cm stubble height and fresh weights recorded. A 300-g subsample was dried at 55°C for 48 hours to determine moisture percentage at harvest. A combined analysis of variance was calculated with data from each location and year.

Experiment 2: Fertilizer Response: Alamo switchgrass was established on a Windthorst fine sandy loam soil at Stephenville and on a Parrita sandy clay loam soil at Beeville in 1992. Fertilizer rates of 0, 50, 100, 150, and 200 kg N ha^{-1} and 0, 20, 40, 60, and 80 kg P_2O_5 ha^{-1} were applied each spring. Within fertilizer treatment whole plots, three row spacing treatment subplots were established. Row spacing treatments were 25, 50, and 100 cm at Beeville, and 18, 36, and 72 cm at

Stephenville. Fertilizer treatments (N and P_2O_5 combinations) were arranged in an incomplete factorial with two replications. Plots were harvested in the fall to determine biomass yields. Soil samples were taken before the experiment began and in the spring of 1995 to monitor nutrient changes.

Experiment 3: Harvest Frequency: Field plots of Alamo switchgrass were established at Dallas and Stephenville in the spring of 1992. In 1993, treatments of four harvest frequency systems and three final fall harvest dates were imposed. System 1 was clipped three times (May, June, July), System 2 was clipped twice (May, June), and System 3 was clipped once (May), whereas System 4 was not harvested during the summer. In the autumn, one-third of each plot was harvested in either September, October, or November. Plots received 67 kg N ha^{-1} in 1993 and 167 kg N ha^{-1} in 1994.

Biomass yield was measured at each harvest and plant and tiller densities were determined also. The experimental design was a randomized complete block with a split plot arrangement of treatments in three blocks. Harvest systems were whole plots and final fall harvest dates were subplots.

Results

Experiment 1: Cultivar and Germplasm Evaluations: Alamo switchgrass was the highest yielding cultivar in 1993 and 1994 (Table 1). Caddo and Cave-in-Rock were the lowest yielding cultivars in each year. Alamo is a lowland ecotype and was developed by the USDA Natural Resources Conservation Service (NRCS) from plant material originally collected in south Texas (USDA-SCS, 1991). Caddo is an upland ecotype developed from plant material collected in Oklahoma (USDA-SCS, 1991) and Cave-in-Rock was released by the NRCS and developed from germplasm collected in southern Illinois. Caddo and Cave-in-Rock matured in June, whereas the other switchgrasses matured in August and September. PMT-279 and PMT-785 were collected by the NRCS but were not released. NCSU-1 and NCSU-2 are unreleased breeding lines from North Carolina. Thus, Alamo is the best cultivar for biomass production in Texas.

Experiment 2: Fertilizer Response: Biomass yield of Alamo switchgrass increased with increasing N rate at each location in each year (Fig. 2). Biomass yields were lower in the initial years at Stephenville (1992) and Beeville (1993), probably because the stand had not yet fully established. Yield responses in subsequent years were greater than in the initial years.

There was a small response to 20 kg of P_2O_5 ha^{-1} at Stephenville in 1992, but there was no response to P fertilizer at Stephenville in 1993 or 1994 or at Beeville in 1993 or 1994. Soils at both locations were low in P (less than 10 kg ha^{-1} of available P in the surface 30 cm of soil according to soil test). The lack of response of switchgrass to P fertilizer indicates that switchgrass is a very efficient user of P, which may be a result of colonization of switchgrass roots by vesicular-arbuscular mycorhizae (Brejda et al., 1993). These mycorhizae may increase plant uptake of P from the rhizosphere at low soil P levels. Analysis of the surface 7.5 cm of soil at Beeville and

Stephenville in 1995 indicated a small increase in available P with increasing P rate; however, levels were not different from the initial soil test. Analysis of soil down to 30 cm indicated no downward movement of P.

There was no yield response to row spacing at Stephenville. At Beeville, there was a N by row spacing interaction in 1993. There was a greater response to N fertilizer at narrrow than wide row spacing. Yield decreased as row spacing increased at Beeville. Sladden et al. (1995) reported a an interation of row spacing and N rate in Alamo switchgrass in Alabama. They reported that the biomass yield increase due to an increase in row spacing was greater at higher N levels.

Experiment 3: Harvest Frequency: At both Dallas and Stephenville, increasing harvest frequency reduced total season biomass yields of Alamo switchgrass (Fig. 3). The highest yields at both locations were obtained with a single harvest in September. Delaying the final fall harvest until October or November reduced yields. Similar decreases in biomass yields of switchgrass were reported by Parrish and Wolf (1992) in Virginia. They suggested that switchgrass remobilized and translocated compounds to the below ground portion of the plant during the fall, partially accounting for the yield loss.

In the multiple harvest systems, about 40% of the yield was obtained at the first harvest in May. Thus, an early harvest of switchgrass to provide forage for livestock on a diversified farm probably will limit biomass yields from regrowth. An alternative may be to delay harvest of switchgrass for biomass until June, and then use the limited regrowth for grazing or hay production in late summer and fall.

Conclusions

1. Alamo is the best adapted switchgrass cultivar for Texas.
2. Switchgrass responded strongly to N, but not P or row spacing.
3. Frequent harvests reduced biomass yields of switchgrass.

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Table 1. Biomass Yields of Eight Switchgrasses in Texas. Data are Averages of Six Locations in Each Year.

Entry	1993	1994
	kg dry matter ha^{-1}	
Alamo	10674	15700
Kanlow	7488	12725
PMT-279	7053	13208
PMT-785	9274	13270
NCSU-1	8669	11400
NCSU-2	6953	11960
Caddo	5752	6423
Cave-in-Rock	4947	5826
L.S.D. (0.05)	1539	1818

L.S.D. = least significant difference at the 0.05 probability level.

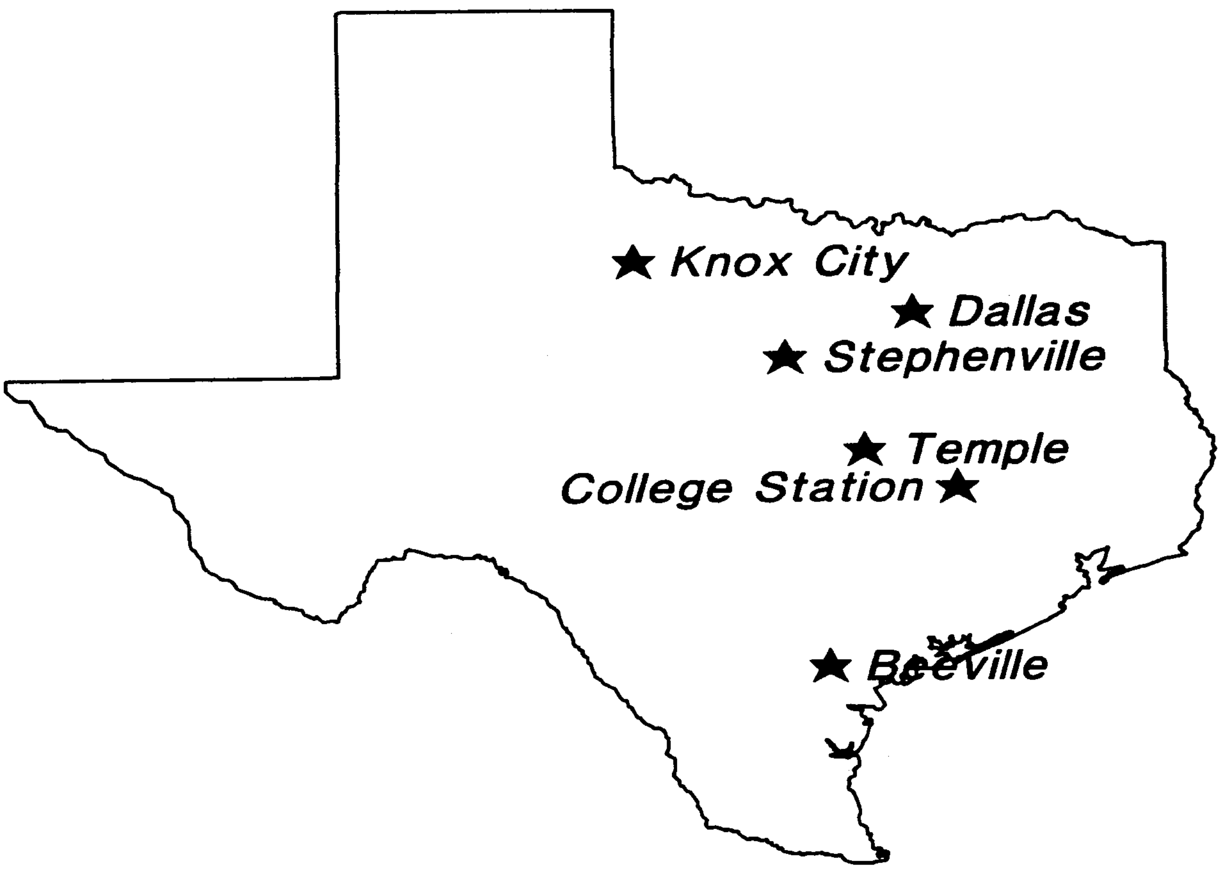

Figure 1. Location of switchgrass biomass research sites in Texas.

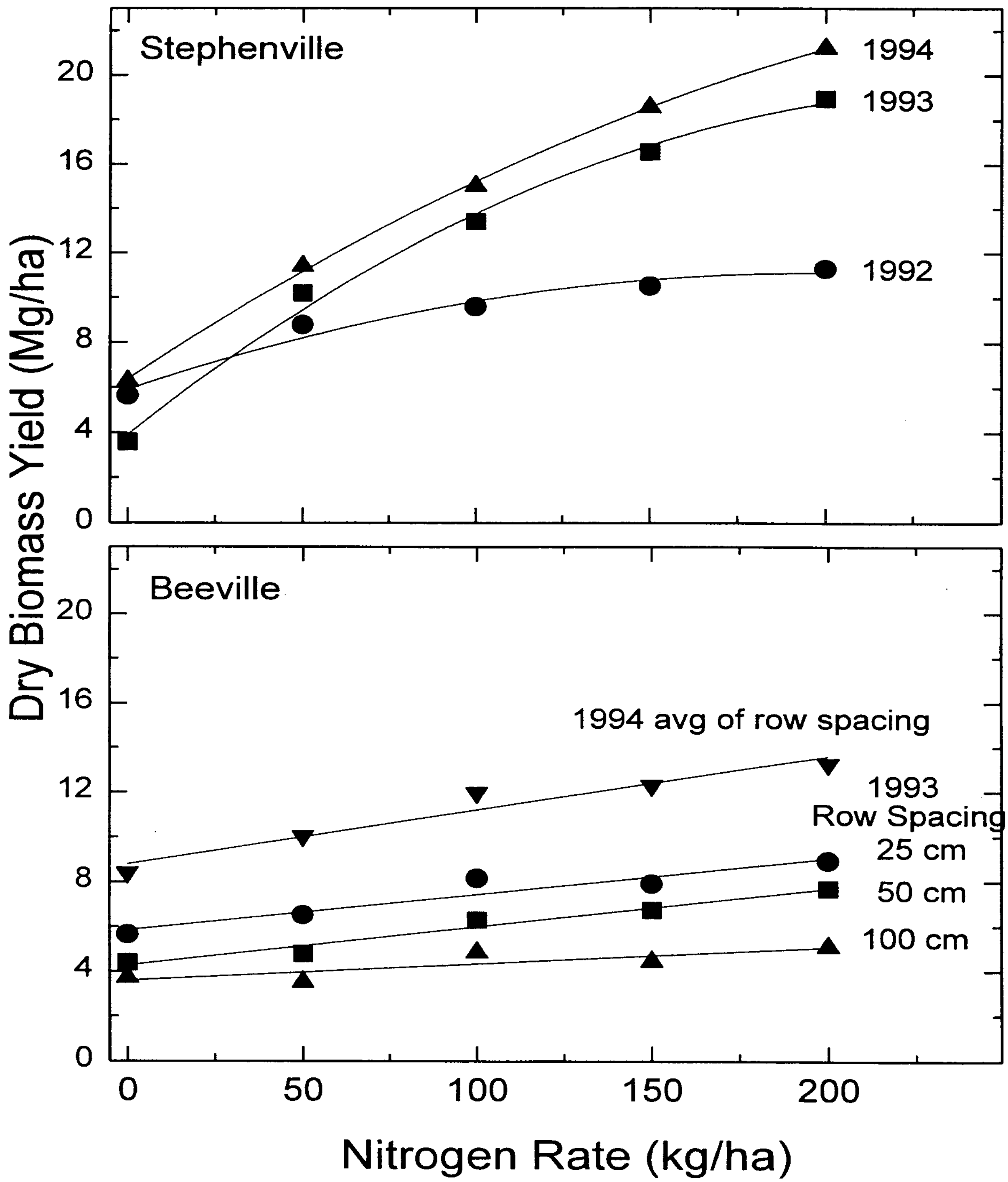

Figure 2. Response of Alamo switchgrass to N fertilizer and row spacing at Stephenville and Beeville, TX.

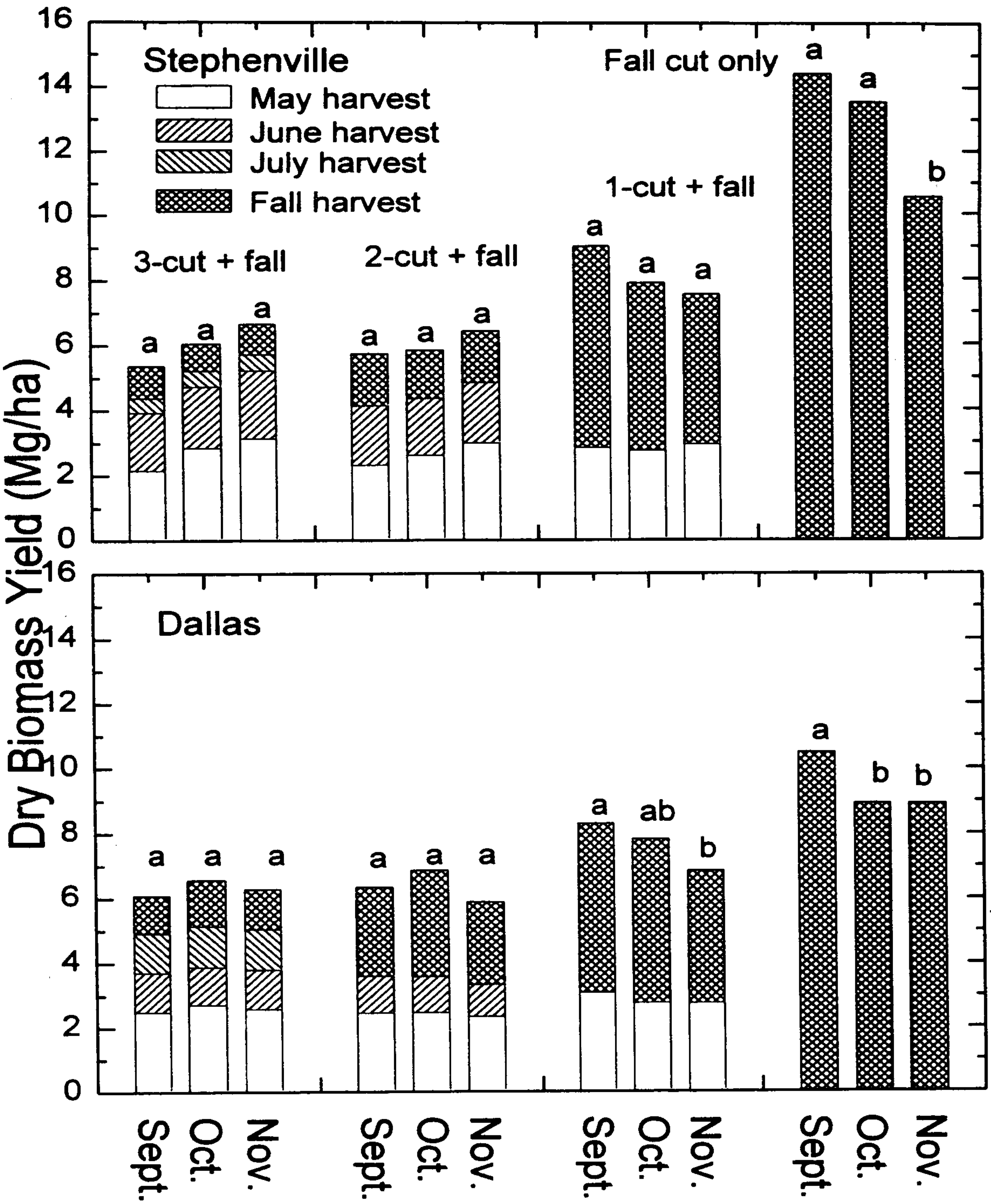

Figure 3. Response of Alamo switchgrass to harvest schedules at two locations. Data are averages of 1993 and 1994. Means within cutting systems with similar letters are not significantly different (P > 0.05). Sept., Oct., and Nov. refer to the month of final fall harvest.

THE NEED AND POTENTIAL TO FURTHER RAISE SWITCHGRASS YIELDS BASED ON 10 YEARS OF RESEARCH IN ALABAMA

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Abstract

Return per acre (and not cost per ton of biomass) is probably the most important economic driver in the development of a future energy crop industry. Because biomass yield per acre strongly affects return per acre, there is a great need to further raise switchgrass yields. Based on progress in Alabama over the first 10 years, there appears to be considerable potential to achieve this goal. Research started in 1985 with the variety 'Cave-in-Rock'. Average yield from mature stands in these experiments was 3.2 tons/acre. However, in 1987 the potential of an alternate variety called 'Alamo' was recognized. From 1990 to 1994 yield of this variety averaged 11.5 tons/acre, while that of Cave-in-Rock was 4.9 tons/acre. This represented a 135% increase. In a more recent experiment, combined effects of increasing row spacing from 8 to 32 inches and nitrogen fertilizer from 100 to 200 lb/acre, increased yield by another 69%. Since work on breeding and selection of switchgrass for biomass has only just started, and additional progress is likely from improved management/cultural practices, it seems reasonable to expect further yield increases of 50-100% in the next 10 years.

Introduction

The general objective of developing energy crops is to generate energy, agricultural, environmental and rural economic development benefits. Clearly, in order to be successful, initiation and expansion of this industry needs to economically driven. The herbaceous energy crops program at Auburn University was initiated in 1985 (Bransby et al, 1990) as part of a national program administered by the Biofuels Feedstock Development Program at Oak Ridge National Laboratory, Oak Ridge, TN. At that time, the target yield for the year 2000 was 10 tons/acre. Following the first phase of the program, switchgrass (*Panicum virgatum*) was chosen as a model herbaceous energy crop for further development. Over the last five years (1990-1994) yields from 'Alamo' switchgrass in research plots in Alabama have average 11.5 tons/acre. Since this exceeds the original target yield of the program for the year 2000, the objective of this paper is to discuss the need and potential to further raise yields of switchgrass for energy.

The Need to Raise Yield

Effects of Yield on Profit per Acre

Given that development of energy crops needs to be driven by economic incentives, factors which have the greatest economic impact should receive proportionate investments in research. As for most field crops, such as corn, soybeans, and wheat, which have been developed by both private industry and the USDA, the focus of the switchgrass research program has been to increase yield. The logic of this is that yield probably has a greater impact on profit for the farmer than any other factor. However, this philosophy was questioned by Cundiff and Harris (1995) who suggested that for switchgrass grown for energy, this may not be true. The basis for their suggestion was a study that showed only a 15% reduction in cost/ton from a 100% increase in yield. They also claimed that energy crop feedstock supply is an equipment-based (rather than a land-based) enterprise, apparently implying that there is more to be gained by cutting harvest costs than by increasing yield. Similar sentiments were expressed in an earlier publication (Cundiff, 1994).

Then why are these authors out of line with the well established view that crop yield is probably the factor which most affects the economics of an agricultural commodity? The answer is that they have encountered several common pitfalls in their analysis: (a) they have made several assumptions which are probably not correct, (b) they have used percentages, which often distort results, and (c) most importantly, they have focused their assessment on cost per ton instead of profit to the farmer.

One of the most important of their assumptions is that harvesting and hauling will be done on a custom basis. A recent survey among farmers indicated that this is probably not true (Sladden and Bransby, 1995). In addition, they claim that "Analysts reporting the influence of a yield increase on production cost correctly state that doubling the yield reduces production cost by 50%", but that "the conversion side of the industry defines production cost as price paid for feedstock delivered to the plant gate". This latter assumption is correct only if the conversion industry also owns the feedstock supply system. However, this is highly unlikely: farmers are expected to control the feedstock supply, and conversion facilities are expected to be responsible mainly for conversion of the feedstock to energy. Therefore, cost of providing the feedstock, and more importantly, the related profit, is of interest to the farmer, while profit from converting it to energy is the prime interest of the conversion facility. The question, then, is how does yield affect profit for the farmer? Clearly, this is important in order to develop the industry.

Cundiff and Harris (1995) assumed annual switchgrass production costs to be $46/acre, and custom harvesting to be $25/ton. They indicated that current custom rates range from $16 to $30/ton. Therefore, it seems reasonable to assume that if farmers performed this function themselves, it could probably be done for $12/ton. Using these figures ($46/acre for annual production costs and $12/ton for harvesting) and a farm gate price of $30/ton, data in Table 1 were generated.

Table 1. The Influence of Switchgrass Yield on Costs, Income and Return to Land and Labor for Farmers.

	Yield (tons/acre)					
	4	6	8	10	12	14
			$			
Total Cost/ton	24	20	18	17	16	15
Total Cost/acre	94	118	142	166	190	214
Total Income/acre	120	180	240	300	360	420
Return/acre to land and labor	26	62	98	134	170	206

These data illustrate several important points. First, cost per ton is not influenced strongly by yield. This supports the observation of Cundiff and Harris (1995). However, cost per ton is not important to the farmer: profit/acre is the driving economic variable. The second point, therefore, is that return/acre rises sharply with yield. Specifically, it increases by $18 for every ton/acre increase in yield. On a 200 acre field, this translates into $3,600 for every ton/acre increase in yield. Clearly, these projections assume that yield is increased at no cost, by factors such as improved varieties of switchgrass, or modified cultural practices, such as spacing of rows.

The final point relating to the data in Table 1 is that yield increases above current yields have a greater effect on return/acre than reduction in harvest costs. For example, if yield is increased from 8 to 10 tons/acre (a 25% increase), return/acre goes up by $36, while if harvest costs at 8 tons/acre yield are reduced from $12/ton to $9/ton (a 25% decrease), return/acre increases by $24/acre. However, what is more important here is that the opportunity and potential to increase yields is probably considerably greater than the opportunity to reduce harvest costs.

Other Effects of Increased Yield

If it is accepted that yield has a critically important effect on return/acre, and return/acre is the most important economic variable to farmers, then increased yield will play a crucial role in achieving the general aims of a bioenergy industry. First, increased yield and returns/acre will make switchgrass for energy more competitive with existing farm enterprises. Once again, this is essential for initiation of the industry. If projected returns/acre are $50 - $100, switchgrass would be expected to replace low-return enterprises, like beef production from pastures and forestry, which earn mostly less than $50/acre. Secondly, greater environmental benefits would be obtained if switchgrass replaced annual row crops. This would require higher yields and a return/acre of $100 or more.

Finally, and perhaps most importantly, increased yield and return/acre will have a crucial effect on rural development through its effect on land values, especially in low-return agricultural regions. The value of land is strongly tied to its earning capacity. For example, in the southeastern USA where forestry and pasture-based beef production dominate most of the area, returns/acre are $25 - $50 and land prices are mostly $250 to $500/acre. In contrast, in the mid-West where corn and soybeans are capable of returns between $150 and $200/acre, land prices range from $1500 to $2000/acre. Therefore, if switchgrass for energy replaced beef pastures in the Southeast, and was capable of returning around $100/acre, land prices should increase to near $1000/acre. This, in turn, would result in doubling the county taxes from that land, and an improvement of many desperately needed services such as education in economically depressed rural areas. These indirect benefits of switchgrass for bioenergy are often overlooked.

Potential to Increase Yield

Although it is near impossible to determine exactly how much yield of switchgrass can be increased at this time, evidence available suggests that there is great opportunity and potential to make substantial progress towards this goal over the next ten years. To illustrate this, research progress in Alabama over the last ten years serves as a useful example.

The switchgrass variety, Cave-in-Rock, was selected for the original species screening trials which were planted at four locations in Alabama in 1985. This variety was chosen because of availability of research data, its success for forage production, and its apparent resistance to disease. However, Cave-in-Rock was developed in the mid-West, and there was little research information available on varieties of a southern origin. Mature stand yields for Cave-in-Rock switchgrass (1987-1989) averaged 3.2

tons/acre across the four locations in Alabama (Bransby et al, 1990). Furthermore, there was virtually no increase in yield with increased nitrogen (N) fertilizer beyond 100 lb N/acre.

Based on observations, certain southern varieties of switchgrass (which were considered unsuitable for forage due to their coarse stems) appeared to have greater biomass potential in Alabama than Cave-in-Rock. Therefore, a new switchgrass variety experiment was established in Alabama in 1988. In this experiment average yields over the last 5 years (1990 to 1994) were 4.9 tons/acre for Cave-in-Rock and 11.5 tons/acre for Alamo switchgrass. This represented a 135% increase in yield, simply by selecting the best variety. However, it also demonstrated the enormous genetic variation in the species, and suggests substantial potential to increase yields further by plant breeding and selection.

Further visual observations stimulated another more recent experiment: spaced plants of switchgrass in a nursery seemed to be more vigorous than plants grown in solid stands. Therefore, a trial was planted in 1992 to determine the interactive effects of row spacing and N fertilization on yield of Alamo switchgrass. The experiment compared row spacings of 8 and 32 inches, each fertilized with 0, 100 and 200 lb N/acre. So far, yields from this study have been lower than those quoted earlier, primarily due to a less mature stand, less favorable weather and a poorer soil. However, relative differences should be transferable.

At the time this trial started, our recommendations would have been an 8 inch row spacing, fertilized with 100 lb N acre. In 1994 yield from this treatment in the experiment was 5.7 tons/acre. Increasing row spacing at the same level of N fertilization increased yield by 23%, to 7.0 tons/acre (Sladden et al., 1995). Increasing N fertilization from 100 to 200 lb/acre at the 32 inch row spacing increased yield by another 46%, to 9.6 tons/acre, while the same increase in N at the 8 inch spacing resulted in only an 18% increase, to 6.7 tons/acre. Therefore, in combination, increasing row spacing and N fertilizer resulted in a 69% increase in yield, and it is possible that this difference could increase further as the stand matures. Clearly, there is no cost associated with the change in row spacing, but additional income from increased yield related to fertilizer will be partially offset by increased costs.

Summary and Conclusions

Because of its powerful effect on economic return/acre, yield of switchgrass is probably the most important production factor which will determine economic viability and impact of switchgrass for energy production. Over the first 10 years of research, a combination of selecting an alternative variety, increasing row spacing and increasing N fertilization has resulted in a total increase of around 200% in yield. Given this progress and the early stage of switchgrass research, it seems reasonable to expect another 50 to 100% increase in yield (compared to Cave-in-Rock) from plant breeding and selection, and improved production practices over the next 10 years.

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COMPOSITIONAL VARIABILITY IN HERBACEOUS ENERGY CROPS

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Abstract

Before large scale production of biofuels can begin, it is necessary to assess the effect of feedstock variability on biomass conversion. Experiments have been performed to determine the degree of compositional variability in different species of herbaceous energy crops. Considered in these studies were the effects of genetics, growing environment, and plant structure. Analytical pyrolysis-mass spectrometry was used to initially screen the samples. Chemical analysis was performed on selected samples to determine the concentrations of structural (cellulose, hemicellulose, and lignin) and non-structural (extractives, ash, and protein) components so that summative compositions were obtained.

Large differences in composition were found between stems and leaves, with leaves having much higher concentrations of non-structural components. The geographic location where plants were grown was also found to have an impact on composition that transcended differences between varieties. The differences between varieties could not be detected above the variability observed in samples from replicate plots of the same variety, if all samples came from the same location.

Introduction

The U.S. Department of Energy has embarked on a major program to develop the basic research and development strategies which will lead to the production of liquid fuels and chemicals from renewable resources. As part of this objective, the production of liquid fuels such as ethanol and bio-oil from terrestrial biomass resources, has been a major focal point. An objective of the Feedstock Research task in the Terrestrial Biomass Feedstock Interface (TBFI) project of the NREL Biofuels program is to assess available and developing lignocellulosic feedstocks for selection of suitable candidates for conversion into ethanol and other biofuels. The information from this task will also assist the Biofuels Feedstock Development program in developing improved dedicated biomass crops. Data are being generated for representative feedstocks that have the potential to supply a significant fraction of U.S. energy needs on a regional or national basis.

Before any large scale biofuels production can begin, it is necessary to assess the effect of feedstock variability on the suitability of biomass feedstocks for conversion to biofuels. An important part of the study of feedstock variability is the study of compositional differences that exist not only between different species but also between varieties of the same species, and that occur due to the environmental conditions under which the biomass was grown, harvested, and stored. The differences in composition between different plant parts, particularly leaves and stems, are also of interest.

Experimental

In this study, chemical analyses were performed to determine the concentrations of structural (cellulose, hemicellulose, and lignin) and non-structural (extractives, ash, and protein) components in biomass samples, so that summative compositions could be obtained. The procedure used involved ethanol extraction of the biomass, followed by a two-stage acid hydrolysis of the extracted material to break down the polysaccharides into their constituent monosaccharides. The monosaccharides were then converted to their alditol acetates prior to gas chromatographic (GC) quantitation. The acid hydrolysis also produced an acid-insoluble residue that contained acid-insoluble ash, klason lignin, and protein-derived material. The ash content of the acid-insoluble residue was measured and nitrogen analysis was performed on the feedstock to estimate protein content (by multiplying N% by 6.25). Nitrogen contents were determined by Huffman Laboratories, Golden, CO. The lignin content was estimated by adding the acid-soluble lignin content to the acid-insoluble residue amount and then subtracting the ash content of the acid-insoluble residue and the estimated protein content of the feedstock. The compositional analysis procedure follows that described in detail by Agblevor (1993a).

Samples were also characterized by a rapid analysis technique, pyrolysis-mass spectrometry using a molecular beam mass spectrometer (Py-MBMS), as described by Agblevor (1993b). In this method biomass samples were rapidly pyrolyzed at 550°C in a flowing stream of helium. The residence time of the pyrolysis products in the reactor was very short (~75 ms); thus, thermal cracking of the primary pyrolysis products was minimized. The pyrolysis vapors were cooled and collimated into a molecular beam and then analyzed in real time using a triple quadrupole mass spectrometer (Extrel™ Model TQMS C50). Low voltage (22 eV) electron impact ionization was used as the ionization source. Mass-spectrometric data were acquired in the range of 15-300 da. The raw mass spectral data were then processed by averaging the spectra across the pyrolysis wave and subtracting the background noise from the averaged data. Mass spectral data acquired from the pyrolysis process were analyzed by multivariate statistical techniques, using data normalized to the total ion current (TIC). The data were correlated around the origin to extract the relative fractional concentrations of compound classes in the biomass pyrolysis products. Factor analysis was performed to select significant factors (eigenvalues >1).

Results and Discussion

Results from four experiments are discussed here. The first compares the compositions of stems and leaves of three varieties of switchgrass grown at two locations. Secondly, the variability in composition between six switchgrass varieties grown at three locations was examined. Thirdly, the compositions of stems and leaves of two genotypes of big bluestem were compared. Lastly, the variability in composition of tall fescue was studied.

Comparison of the Compositions of Stems and Leaves of Switchgrass

For this experiment whole switchgrass (*Panicum virgatum* L.) plants were obtained from Auburn University, AL, and Virginia Polytechnic Institute, Blacksburg, VA. The switchgrass samples included two lowland varieties, Alamo and Kanlow, and one upland variety, Cave-in-Rock (CIR). The plants were harvested in July 1992, at the anthesis stage of maturity, when the plants had just finished flowering, at the end of maximal biomass growth and the beginning of seed growth. The plants were separated into stem and leaf fractions. There was no apparent correlation of variety or location with the mass fractions of leaf and stem biomass (Table 1).

There were considerable differences in the dry matter yields (Mg ha^{-1}) observed at Auburn with these varieties. The average combined (July + October harvests) yields from 1989 to 1992 were 10, 17, and 26 Mg ha^{-1}, for CIR, Kanlow, and Alamo, respectively. Normally about 2/3 of the total yield is obtained from the July harvest. The 1992 growing season (April to October) was close to average in biomass yield, ambient temperature (average mean air temperature 21°C), and precipitation received (71 cm).

Factor analysis of the compositional data identified two significant factors responsible for resolving the difference in composition between stems and leaves. The leaves contained higher levels of the non-structural components, protein, ash, and extractives, as well as minor hemicellulose components. Stems contained higher levels of the major structural components, glucan, xylan and lignin. There appeared to be some distinction between the locations at which the feedstocks were grown. There was no apparent dependence of composition on variety, despite the large differences in yields for the different varieties. The data in Table 1 shows the ranges in composition in stems and leaves across all three varieties grown at each location. The leaves contained about twice the ash, and two to four times the protein, of stems. Leaves were also higher in extractives (by about 5%),

Table 1. Stem and Leaf Composition Ranges (Weight %, on an Oven Dry Basis (% ODW)) for Three Switchgrass Varieties Grown at Two Locations

Production Location	Auburn, AL		Blacksburg, VA	
	Stems	Leaves	Stems	Leaves
Mass Fraction	61 - 70	30 - 39	65 - 69	31 - 35
Extractives	11.7 - 16.2	16.5 - 24.2	11.5 - 15.6	10.8 - 20.6
Ash	2.6 - 3.6	5.2 - 5.7	2.3 - 2.6	4.5 - 5.4
Lignin	13.6 - 16.0	5.5 - 10.0	16.6 - 17.2	8.7 - 15.4
Protein	1.9 - 3.2	5.8 - 9.0	1.8 - 1.9	4.4 - 8.5
Arabinan	2.3 - 2.7	3.2 - 3.5	2.2 - 2.4	3.3 - 3.7
Xylan	21.9 - 24.0	17.6 - 19.4	21.8 - 25.0	19.1 - 21.8
Galactan	0.6 - 0.8	1.2 - 1.4	0.6 - 1.2	1.6 - 2.6
Mannan	0.2 - 0.3	0.2 - 0.4	0.2 - 0.4	0.4 - 0.6
Glucan	33.5 - 37.5	26.8 - 30.9	35.8 - 37.1	27.8 - 33.8
Mass Closure[1]	100 - 102	97 - 100	101 - 103	98 - 101

[1] Includes 2% for the uronic acid and acetyl components of the hemicelluloses.

and arabinan (by about 1%). Stems were higher in the structural components, lignin (by about 6%), xylan (by about 4%) and glucan (by about 6%).

Comparison of the Compositions of Six Switchgrass Varieties Grown at Three Locations

In this experiment samples of whole switchgrass plants that had been dried, milled, and screened (-20/+80 mesh), were obtained from the U.S. Department of Agriculture-Agricultural Research Service (USDA-ARS), Lincoln, NE. Six upland varieties of switchgrass, Blackwell, Cave-in-Rock, Cave-in-Rock High, Trailblazer, EY x FF High C3, and EY x FF low C1, were used in this study. All six varieties were produced at each of three different geographical locations: Mead, NE; Ames, IA; and West Lafayette, IN. There were four replicate plots for each variety at each location. The samples for this study were harvested at heading (when half the panicles in a plot emerged from the flag leaf collar) between August 3 and August 11, 1992.

Data on the biomass yields for all six varieties at each of the locations are incomplete. For CIR the yields ranged from 13 to 14 Mg ha^{-1} at each location. For the other varieties, not all of which were included in the composition study, yields ranged from 4.5 to 15 Mg ha^{-1}. At all three locations there were always several varieties at the upper end of this range, from 13 to 15 Mg ha^{-1}. At all three locations, the 1992 growing season (April-September) appeared to be cooler than average (by about 2°C), with the average mean air temperature at each location being about 17°C. Precipitation varied between the locations with Mead, NE, receiving only about 2/3 of its normal level of 62 cm. The other two locations received close to normal precipitation levels of about 60 cm.

Surprisingly, the low level of precipitation received at Mead, NE, did not appear to affect biomass yields.

The set of 72 samples in this study was initially screened by Py-MBMS to determine if there were trends in the composition of these switchgrass samples. Based on the trends observed, a subset of samples was selected for chemical analysis. Several experiments were conducted that showed there was no difference between samples from replicate plots of the same variety grown at the same location.

Py-MBMS analysis of samples from one plot of each variety at each location was performed. Factor analysis of this data set indicated that four main factors could account for 75% of the variance in the data set. The factor-score plot of factor 2 vs factor 3 (Figure 1) showed three main clusters corresponding to each of the geographical locations in which the samples were produced. The factor analysis clearly indicates that the largest variability in chemical composition was due to the location in which the samples were grown. The difference between the samples appeared to be largely due to differences in the relative amounts of nitrogen-containing compounds (mostly protein), pentosans, and lignin in the samples. No significant difference between varieties was observed.

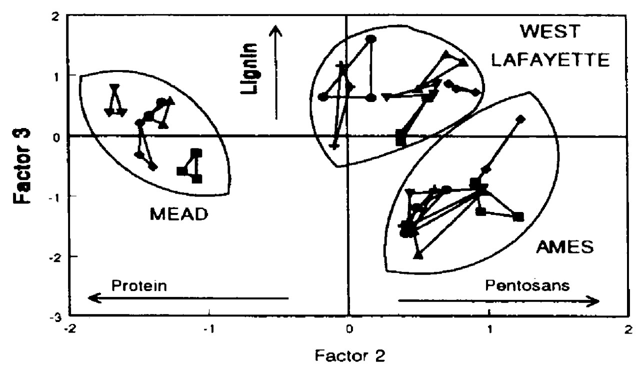

Figure 1. Factor-score plot of Py-MBMS data comparing six switchgrass varieties grown in three different geographical locations. ▽) EY x FF high C3. △) Trailblazer. ◻) EY x FF Low C1. ○) Cave-in Rock. ◇)Blackwell +)Cave-in-Rock High. Triangles connect the points from triplicate Py-MBMS experiments.

For chemical analysis, 18 samples were selected to test the location dependence observed using Py-MBMS. Table 2 shows the ranges in concentrations of the various components across all varieties at each of the locations. The data show that there were relatively small differences in the composition of the samples from the different locations. In general, the chemical analysis data agreed with the results from the Py-MBMS. Samples from Mead were lowest in pentosans (by about 1:5%). Switchgrass grown at West Lafayette had the lowest protein content (by about 1%), but was highest in lignin (by about 2%). Compositional analysis found that samples from the Ames location were lowest in glucan content (by about 1%), but had the highest extractives content (by about

2%). Py-MBMS indicated a relatively high hexosans content for the Ames samples. The resolved component for hexosans is influenced by the amounts of hexosans in both the extractives and cellulose, so that the Py-MBMS result is due to the higher overall concentration of hexosans in the switchgrass. The biggest difference between the chemical and Py-MBMS data was that the Py-MBMS method more clearly resolved the samples into groups corresponding to the locations where they were grown. The reason for the better resolution of the Py-MBMS method is not understood at this point.

Table 2. Composition Ranges (% ODW) for Six Switchgrass Varieties Grown at Three Different Locations

Production Location	Ames, IA	Mead, NE	W. Lafayette, IN
Extractives	10.8 - 16.4	6.4 - 13.8	7.4 - 13.6
Ash	6.3 - 7.5	6.3 - 7.4	5.5 - 7.6
Lignin	9.9 - 12.1	10.8 - 13.5	12.6 - 14.9
Protein	5.8 - 6.9	6.0 - 7.9	4.6 - 6.0
Arabinan	3.0 - 3.3	2.9 - 3.1	3.0 - 3.2
Xylan	21.8 - 24.0	20.9 - 21.9	22.3 - 23.8
Galactan	1.0	1.0 - 1.2	0.9 - 1.1
Mannan	0.2 - 0.4	0.2 - 0.4	0.1 - 0.5
Glucan	31.2 - 32.8	32.6 - 34.4	32.9 - 34.2
Mass Closure[1]	97 - 101	95 - 99	95 - 99

[1] Includes 2% for the uronic acid and acetyl components of the hemicelluloses.

At this time, the environmental factors that were most influential in determining the chemical compositions of the switchgrass samples are not known. All samples were harvested at the same time of year and at the same maturity levels. The Mead location appears to have several environmental factors that could have influenced the chemical composition to a greater degree than the other locations. Prior to the spring growth period in 1991, the plant residue was removed (by burning) from only the Mead location. The Mead location also had a higher amount of weed growth and greater amounts of weed-killing herbicides applied. Possibly the most important factor was that the Mead location experienced a -20 cm deviation from its average rainfall of 62 cm while Ames and West Lafayette received close to average rainfall (~ 60 cm for both locations).

There are some significant differences between these samples and the switchgrass samples obtained from Alabama, Virginia, and Texas. Only one upland variety was common to both studies, Cave-in-Rock (CIR). It appears that the samples from the USDA-ARS Nebraska study were significantly higher in ash (by about 3%) and protein (by about 2%).

Biomass yields for the upland varieties from the USDA-ARS study were significantly higher than yields reported for the CIR grown at Auburn (by about 4 Mg ha^{-1}). The higher yields were very surprising as the locations used in the USDA-ARS study are further north, giving them a significantly shorter growing season. In addition, the ambient temperature and precipitation levels of the more northerly locations were significantly lower (by about 4°C and 10 cm, respectively). A possible explanation of the relatively high biomass yields and composition differences is that there may have been higher levels of fertilizer used at the more northerly locations. In the USDA-ARS study 112 kg N ha^{-1} was applied as ammonium nitrate, in addition to some phosphorous and potassium.

Comparison of the Compositions of Stems and Leaves of Big Bluestem

Samples of two genotypes of big bluestem (*Andropogon gerardi, A. fercatus*) were obtained from Auburn University. The samples came from duplicate plots of two genotypes, one from Greene County, AL, and the other from Baldwin County, GA. The plants had been separated into stem and leaf fractions, and had already been milled and sieved when received. Screening by Py-MBMS showed the expected large difference in composition between stems and leaves (Figure 2). Most of the difference was due to the components making up Factor 2. The stems were higher in lignin and hexosans, while the leaves were high in protein. One sample of leaves appeared to be an outlier compared to the rest of the leaf samples, having a relatively high carbohydrate content.

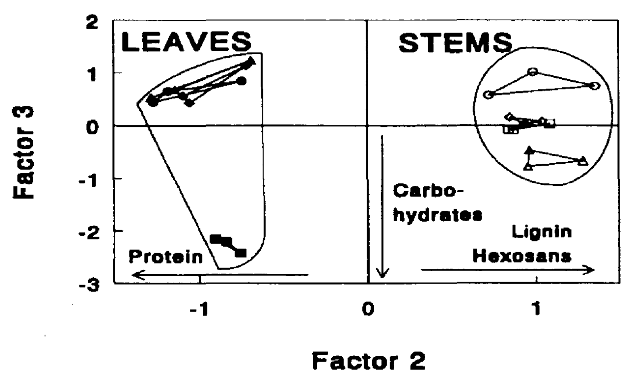

Figure 2. Factor score plot of Py-MBMS data comparing stems and leaves of four big bluestem samples. Greene County, AL, genotype, plot 1010 (◊) and plot 2336 (△). Baldwin County, GA, genotype, plot 1355 (O), and plot 1735 (□). open symbols, stems. filled symbols, leaves. Triangles connect the points from triplicate Py-MBMS experiments.

Table 3 shows the range of compositions of the stems and leaves across all four samples. The leaves appeared to contain twice the protein (higher by about 3%) and significantly more of the minor hemicellulose components, arabinan (~ 0.8%) and galactan (~ 0.7%). Ash content was also higher (~ 1.5%) in the leaves of all but one of the samples (leaves and stems from plot 1010 of the Greene County, AL, genotype). The stems appeared to be higher in the structural carbohydrates xylan (by about 5%) and glucan (by about 4%). These differences between stems and leaves are similar to the differences seen between switchgrass stems and leaves. In addition, the overall compositions of switchgrass and big bluestem appear to be very similar. With so few samples it was not possible to determine if the different genotypes had significantly different compositions.

Table 3. Stem and Leaf Composition Ranges (Weight %, on an Oven Dry Basis) for Big Bluestem

	Stems	Leaves
Extractives	11.8 - 16.0	10.1 - 19.4
Ash	2.1 - 3.5	2.6 - 5.1
Lignin	12.7 - 17.5	10.1 - 17.8
Protein	2.8 - 4.4	6.2 - 7.8
Arabinan	2.4 - 2.8	3.2 - 3.6
Xylan	21.0 - 22.8	15.7 - 18.5
Galactan	0.6 - 0.8	1.2 - 1.7
Mannan	0.3	0.3 - 0.5
Glucan	34.4 - 37.6	29.0 - 34.0
Mass Closure[1]	99	94 - 96

[1] Includes 2% for the uronic acid and acetyl components of the hemicelluloses.

Study of the Composition of Tall Fescue

Samples of three varieties (John Stone, Kentucky 31, and Martin) of tall fescue (*Festuca arundinacea*) were obtained from Iowa State University, Ames, IA. The tall fescue was first cut on June 1, 1992. Cuts 2 (July 20, 1992) and 3 (September 8, 1992) came from harvests of material that regrew after each cutting. The majority of the regrowth was leaf material with very little stem material being produced after the first cutting. The dry matter yields were significantly lower from the second cutting than from either the first or third cuttings. This was attributed to a particularly dry early summer period. Yields from the first cutting averaged about 4 Mg ha^{-1}. In both the second and third cuttings the Kentucky 31 variety had the highest yields (3.3 and 5.2 Mg ha^{-1}), while the yields of the other two varieties were approximately equal (at about 2.7 and 4.7 Mg ha^{-1} from the second and third cuttings, respectively). Large amounts of ammonium nitrate were applied to fertilize the plots during this study. Near the start of the growing season (March 25, 1992), 109 kg ha^{-1} was applied, and then, after the first and second cuttings, additional amounts (about 100 kg ha^{-1} each) were added.

Screening with the Py-MBMS showed (Figure 3) that there was a significant difference in composition in the materials from cuts 2 and 3. The samples from the second cut appeared to be higher in protein and carbohydrates, while samples from the third cut were higher in lignin.

The chemical compositions of the two tall fescue cuttings (Table 4) reflect the fact that most of the material produced from regrowth was leaf material. The tall fescue material in cuttings 2 and 3 was very high in non-structural components (extractives, ash, and nitrogen). The extractives contents were not only high but also very uniform, unlike switchgrass, which has been observed to have a very broad range of extractives contents. The structural components were present in significantly lower concentrations than other herbaceous feedstocks with glucan contents at about 25%. Mass closures for tall fescue were lower than observed for other feedstocks. It is obvious that the analytical method had problems with this species.

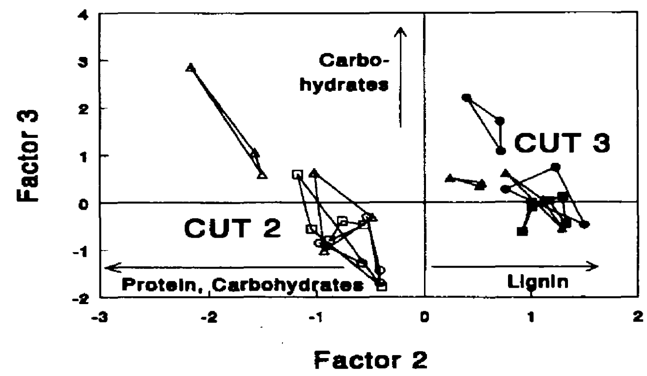

Figure 3. Factor score plot of Py-MBMS data comparing three varieties of tall fescue from two Cuttings. John Stone (O), Kentucky 31 (□), and Martin (▲). open symbols, Cut 2. filled symbols, Cut 3. Triangles connect the points from triplicate Py-MBMS experiments.

Table 4. Composition Ranges (% ODW) for Tall Fescue

	Cut 2	Cut 3
Extractives	19.8 - 20.7	19.7 - 21.6
Ash	10.6 - 11.8	10.2 - 12.1
Acid Insoluble Residue	12.6 - 14.8	10.9 - 14.5
Nitrogen Content	2.2 - 2.5	1.7 - 2.2
Arabinan	2.9 - 3.0	3.0 - 3.2
Xylan	13.8 - 15.3	13.5 - 15.5
Mannan	0.3	0.4 - 0.5
Galactan	1.1 - 1.2	1.3 - 1.5
Glucan	23.4 - 25.6	24.9 - 26.4
Mass Closure[1]	89 - 93	88-94

[1] Includes 2% for the uronic acid and acetyl components of the hemicelluloses.

Py-MBMS analysis found that there was a difference between cuts 2 and 3 based on their lignin contents. An advantage of the Py-MBMS over chemical analysis, is that the Py-MBMS can chemically discriminate lignin from interferences. Literature data on the chemical composition of tall fescue comes solely from forage analysis methods. These methods measure lignin by permanganate oxidation. Typical lignin contents by this method range from 4 to 7%, with values of about 5% common (Brandsby et al., 1989). Nitrogen contents have been reported to range from 1.5 to 3.8%, with values of about 2.2% typical (Brandsby et al., 1989).

Conclusions

In the four studies described here, we have looked for subsets of samples that showed correlated behavior. Apart from the expected large differences between stems and leaves, it was determined that growing location can have the largest impact on composition, transcending the differences between varieties. Consistent differences in composition between varieties across locations were not detected. Some components exhibited more variability than others, even within subgroups of samples with similar composition. The component generally showing the greatest variability was the extractives component (by as much as ± 30% on a relative basis). Protein, ash, and lignin also varied significantly (10-20% on relative basis). The carbohydrate components exhibited the least variability - xylan and glucan contents of samples within the same subgroup were normally within 3-5% on a relative basis. For all components except glucan these levels of variation are substantially above the analytical variability of their quantification.

As different varieties have very different biomass yields, it would appear that yield should be the main factor determining the choice of which variety to plant as a biofuels feedstock. For the species analyzed to date, all varieties within a species appear to be of equal quality at least with regard to their composition. The differences between samples grown at different locations are presumably caused by variability in their environments. Environmental factors that could affect plant composition include soil condition, fertilizer or herbicide application, precipitation received, etc. We have attempted to identify environmental factors that could have caused the composition differences observed. However, no meaningful correlations between environmental effects and plant composition can be made until many more samples are analyzed. These samples must come from enough locations at various times so that the effects of environmental factors can be fully sampled. Another important factor that could affect feedstock composition is plant maturity. To date, our experiments have been designed to look only at plants of the same maturity. In the future, experiments must be performed to examine this potentially important factor determining plant composition.

The most valuable components present in biomass for conversion into fuels are the main structural components, glucan, xylan, and lignin. For ethanol production glucan is obviously the most valuable component. Xylan can also be converted into ethanol; however, the technology for accomplishing this is not completely developed. Lignin is a valuable source of process heat as it has the highest specific heat content (11,300 Btu/lb). It is possible that excess electric power could be generated from lignin combustion to produce co-product revenue (Bergeron and Hinman, 1989). Lignin is a very important component in thermochemical conversion of biomass, as it has the highest carbon content. Glucan and hemicellulose components can also be important. However, the non-structural components can be detrimental to thermochemical fuels production. Ash contains alkali that can cause corrosion of the turbine blades used in generating electric power from the hot combustion gas produced from burning pyrolysis oil (Raymond, 1980; Moses and Bernstein, 1994). High levels of protein can lead to higher levels of char formation (Agblevor, 1993b). Consequently, tall fescue is unlikely to be a good feedstock for biofuels production because of its low cellulose, hemicellulose, and lignin contents, and relatively high extractives, ash, and nitrogen contents.

The data from analyses of switchgrass and big bluestem suggest that plant development should be aimed towards producing plants with less leaf mass and more stem mass. This is opposite to the direction of plant development research to date, which has been aimed at producing plants with a higher ruminant digestibility, favored by higher leaf mass.

Decreasing leaf mass is, however, likely to have detrimental effects. Leaves are essential for photosynthetic plant growth, thus less leaf mass may decrease plant growth rates and biomass yields. It is possible that harvesting strategies could be developed to separate the higher quality stem material for biofuels applications from the leaves that could be used as animal feed or recycled in the field to provide nutrients for the next crop.

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CHEMICAL COMPOSITION OF BIOMASS FROM TALL PERENNIAL TROPICAL GRASSES

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Abstract

The tall perennial tropical grasses, elephantgrass (*Pennisetum purpureum* Schum.), sugarcane and energycane (*Saccharum* sp.) and erianthus (*Erianthus arundenaceum* (Retz) Jesw.) have given very high oven dry biomass yields in Florida and the warm Lower South USA. No good complete analyses of the chemical composition of these grasses for planning potential energy use was available. We sampled treatments of several tall grass demonstrations and experiments containing high-biomass yielding genotypes of the above tall grass crops at several locations in Florida over the two growing seasons, 1992 and 1993. These samples were analyzed for crude protein, NDF, ADF, cellulose, hemicellulose, lignin, and IVDMD or IVOMD. The analysis for the above constituents are reported, along with biomass yields where available, for the tall grass accessions in the various demonstrations and experiments. Particular attention is given to values obtained from the high-yielding tall grasses grown on phosphatic clays in Polk County, FL, the area targeted by a NREL grant to help commercialize bioenergy use from these crops.

INTRODUCTION

The tall perennial tropical grasses elephantgrass (*Pennisetum purpureum* Schum.), sugarcane and energycane (*Saccharum* sp.) have been evaluated in the lower South as energy crops. The longer the warm growing season the higher is the biomass yields of these crops (Prine and Woodard, 1994). Long linear growth periods at growth rates of 18 to 27 g m^{-2} d^{-1} (160 to 240 pounds/A/day) results in accumulative high seasonal yields (Woodard and Prine, 1993). In the subtropical and warmer temperature climates these grasses can grow during the entire warm season without lodging because of large strong stems. The terminal buds of shoots often stay vegetative until frost though some may develop a flower shoot late in fall. Minerals and plant food are translocated from lower leaves which die and often remain attached to plant for entire season. This allows the old dead leaves to dry out after each rainfall, so that they do not rot. In sugarcane harvest for sugar these dead leaves must be burned or stripped off before processing. For energy uses, these leaves have high dry weight and energy, so are harvested with remainder of shoot. The green leaves at top of plant remain photosynthetically active until killed by freezing temperatures.

The oven dry biomass yields of top growth of tall perennial grasses has been high varying from 15 to 48 mg ha^{-1} yr^{-1} (7 to 21 tons/A/yr) in dry matter colder northern portion of production area to 30 to 60 Mg ha^{-1} yr^{-1} (13 to 27 tons A^{-1} yr^{-1}) dry matter in Southern Florida (Prine and Woodard, 1993 and 1994; Stricker et al., 1993). These grasses are perennial but they are tropical and may winter kill in colder zones, so care must be taken to plant adapted cultivars for the planting location. After the top growth freezes or is harvested, the shoots for new season regenerate from underground rootstocks. The life expectancy of adapted tall grass cultivars harvested once a season for bioenergy is considered to be about 5 or 6 growing seasons, though productive stands of some cultivars have been observed that were 10 or more years old.

We were approached about the need for better chemical composition values for the tall grasses for planning various bioenergy activities. Both yields and composition should be helpful in successfully developing the tall grasses for bioenergy crops.

MATERIALS AND METHODS

In 1992 and 1993 we obtained bioenergy biomass samples from field experiments and/or demonstrations planted at three locations in Florida. The first location was on Arredondo fine sandy soil at Green Acres Agronomy farm at Gainesville. The second site, a similar fine sandy soil, was at the Energy Park at Gainesville about 15 miles from the Green Acres site. The third location was planted on phosphatic clay at IMC Headquarters of Mined Lands Agricultural Research/Demonstration Project in Polk County. This latter planting was increase blocks of tall grasses tested on a clay soil earlier by Stricker et al. 1993. The over 100,000 acres of phosphatic clays from phosphate settling ponds in the central Florida area are expected to play a part in any bioenergy crops and industry developed in the region.

Fresh and dry matter biomass yields were determined for the selected tall grass genotypes available at the three locations. The yields were determined from 3.7 to 6.1 meter long single row yield-areas in larger plots. Row width was 91 cm (3 ft.) at Gainesville locations and 152 cm (15 ft.) on phosphatic clay in Polk County. In some cases, the yield row was not bordered properly and environmental enrichment occurred resulting in higher fresh and dry weight yields than would be normally expected.

The fresh grass samples were dried to a constant weight at 60°C to obtain dry weight. Then the dried grass biomass was ground through a hammermill and then reground through a Wiley Mill with a 1 mm screen. The ground sample was divided and one-half of sample was sent to the University of Florida, IFAS Forage Evaluation Laboratory, Gainesville, FL, where samples were analyzed for N, crude protein (CP) and In vitro organic matter digestibility (IVOMD). The second portion of the ground samples was sent to laboratory of W. P. Windham at USDA Richard C. Russell Research Center at Athens, GA where they were analyzed for crude protein, neutral detergent fiber (NDF), acid detergent fiber (ADF), cellulose (CELL), lignin (LIG) and in vitro digestible dry matter (IVDMD). The analyses were made by standard laboratory procedures adapted and used by each laboratory. Hemicullulose (H-CELL) percentage was estimated by subtracting % ADF from % NDF.

RESULTS AND DISCUSSION

The fresh weight and dry matter biomass yields of grasses at various locations that were harvested for yield in 1992 and 1993 are given in Table 1. The yields are from single unreplicated plots and should not be used for comparative purposes. Also some treatments had enriched environments and probably had higher than normal biomass yields . We are including the biomass yields to indicate the productivity of the plants from which chemical compositions are reported in later Tables.

Those mainly interested in biomass yields are referred to papers by Prine and Woodard 1993 and 1994 and Stricker et al. 1993. We have included the fresh weight biomass yields to emphasize the large quantities of plant material and water which must be handled per unit area when these tall crops are harvested direct without drying. The organic matter digestibility of the tall grass biomass for 1992 and 1993 growing seasons as determined at IFAS lab are shown in Tables 2 and 3, respectively. The IVOMD percentages are generally low indicating the high lignin and fiber of these crops.

The chemical composition of various tall grass entries in 1992 growing season is shown in Tables 4 and for 1993 growing season is shown in Table 5. The composition data seem to vary with crop, year and location. With the small number of samples analyzed and the considerable variation, we are not going to draw any conclusions but report these values so that interested parties can use them for their own purposes.

In Table 6, we have attempted some summarization of composition data in Tables 4 and 5 as to the different tall grass crops. The composition of the crops is quite similar and suggests they might be used interchangeably for bioenergy use. Stricker et al. (1995) proposes a bioenergy system in Central Florida where the tall grass crops reported here along with leucaena (Leucaena spp. mainly leucocephala) and eucalyptus (Eucalyptus spp.) are integrated. Sugarcane would be the main feedstock and juice would be extracted and used to make alcohol in conventional manner. Celluse and hemicellulose from sugar cane press cake, elephantgrass, leucaena, and eucalyptus, would be converted to alcohol. Non fermenting residues such as lignin, would fuel the factory. In Table 6, the dried sugarcane is lower in CP, NDF, ADF, H-CELL, CELL and lignin, but higher in sugar (not reported). All our tall grass crops could also be used to make methane if this was the desired energy product. Erianthus is a high yielding crop but difficulty has been experienced in getting satis factory stands of this crop. Until this establishment problem is solved erianthus cannot be considered a dependable crop. The high annual biomass production of the other tall grasses in humid Lower South USA makes them candidates to furnish a major part of energy in any bioenergy system in the region.

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Table 1. Fresh weight and dry matter biomass yields of selected tall grass cultivars at three Florida locations in 1992 and 1993 growing seasons.

Tall grass entry†	Plot location‡	Biomass yield				
		Fresh		Dry matter		
		1992	1993	1992	1993	2 year avg
		(Mg/ha)				
N-51	GA	178*	89*	58*	26*	42*
PI 300086 eg	GA	198*	156*	72*	44*	58*
L79-1002 ec	GA	186*	88*	68*	26*	47*
N-51 eg	EP	65	105	21	30	26
PI 300086 eg	EP	112	78	38	23	31
L79-1002 ec	EP	30	82	10	44	27
S-41 eg	EP	129		44		
Hexaploid X2 eg	EP	101		34		
US 72-1153 ec	EP	100	134	26	44	35
124-A-6 seeded eg	EP	85		28		
US 56-9 ec	ML	129	101	41	32	37
US 78-1009 sc	ML	150	154	38	39	38
CP72-1210 sc	ML	111	108	30	29	30
L79-1002 ec	ML	113	96	38	32	35
US 72-1153 ec	ML	165	142	40	34	37
1K 7647 er	ML	111§	50§	25§	11§	18§
N-51 eg	ML	64§	65§	19§	19§	19§
US 67-2022 sc	ML	199*	166*	54*	45*	50*

† eg = elephantgrass, sc = sugarcane, ec = energycane and er = erianthus and s = sorghum.

‡ Location: GA was Green Acres Agronomy Farm near Gainesville, FL; EP was Energy Park on University of Florida campus at Gainesville, FL; ML was on phosphatic clay at Mined Lands Agricultural Research/Demonstration Project headquarters in Polk County, FL.

* Plot yield rows were not bordered by plants of same size so environmental enrichment occurred, especially for light.

§ Poor plant stand.

Divide Mg/ha by 2.24 to convert to Tons/acre.

Table 2. The organic matter (OM) content, and in vitro organic matter digestibility of tall grasses grown at three Florida locations during the 1992 growing season as analyzed by IFAS Forage Evaluation Laboratory.

Tall grass entry†	Plot location‡	Plant composition and digestibility		
		Dry matter	OM(DM)	IVOMD
		%		
N-51 eg†	GA	92.1	94.2	43.0
PI 300086 eg	GA	92.1	92.8	45.8
L79-1002 ec	GA	91.9	95.5	35.9
N-51 eg	EP	92.1	96.2	38.6
PI 300086 eg	EP	91.6	96.9	40.6
L79-1002 ec	EP	91.3	95.7	42.4
S-41 eg	EP	91.2	98.1	42.4
Hexaploid X2 eg	EP	91.1	97.3	32.0
300086 X Mott eg	EP	90.4	98.1	37.6
US72-1153 ec	EP	91.8	95.6	40.8
124-A-6 seeded eg	EP	91.2	97.6	31.3
US 56-9 ec	ML	91.4	94.6	38.4
US 78-1009 sc	ML	92.3	94.1	44.8
CP72-1210 sc	ML	91.6	94.2	46.8
L79-1002 ec	ML	92.1	92.2	34.6
US 72-1153 ec	ML	91.2	92.3	37.5
1K 7647 er	ML	91.7	92.1	40.0
N-51 eg	ML	92.2	90.0	40.8
US 67-2022 sc	ML	92.5	95.3	60.7

†eg = elephantgrass, sc = sugarcane, ec = energycane, and er = erianthus.

‡Location: GA was Green Acres Agronomy Farm near Gainesville, FL; EP was Energy Park on University of Florida campus at Gainesville, FL; ML was on phosphatic clay at Mined Lands Agricultural Research/Demonstration Project headquarters in Polk County, FL.

Table 3. The organic matter content and organic matter digestibility of tall grasses grown at three Florida locations during the 1993 growing season as analyzed by IFAS Forage Evaluation Laboratory.

Tall grass entry†	Plot location‡	Dry matter	OM (DM)	IVOMD
			%	
N 51 eg	GA	91.9	94.5	42.9
L 79-1002 ec	GA	91.9	95.9	37.1
PI 300086 eg	GA	92.2	93.6	40.7
US 72-1153 ec	EP	91.8	96.1	43.5
N 51 eg	EP	92.6	95.2	40.9
L 79-1002 ec	EP	92.1	94.1	42.7
PI 300086 eg	EP	92.1	96.5	38.7
US 72-1153 ec	ML	92.0	93.3	37.2
N-51 eg	ML	92.2	94.7	31.8
IK 7647 er	ML	92.1	94.9	23.7
US 56-9 ec	ML	92.3	94.6	38.5
L 79-1002 ec	ML	92.8	93.7	31.7
US 67-2022 sc	ML	91.8	94.0	45.2
CP 72-1210 sc	ML	92.3	94.4	43.1
US 78-1009 ec	ML	92.6	94.6	39.3
US 67-2002 sc	ML	92.1	94.0	52.6
Temperate corn st	ML	91.4	97.2	35.1
Tropical corn st	ML	91.2	95.1	40.7

† eg = elephantgrass, sc = sugarcane, ec = energycane and er = erianthus and st = stover.

‡ Location: GA was Green Acres Agronomy Farm near Gainesville, FL; EP was Energy Park on University of Florida campus at Gainesville, FL; and ML was on phosphatic clay at Mined Lands Agricultural Research/Demonstration Project headquarters in Polk County, FL.

Table 4. Chemical composition of tall grasses grown at three Florida locations in 1992 growing season.

Entry†	Location*	Chemical composition**						
		CP	NDF	ADF	H-CELL	CELL	LIG	IVDMD
		%						
N-51 eg	GA	8.19	74.22	44.15	30.07	37.96	6.18	50.69
PI 300086 eg	GA	7.74	71.96	39.57	32.39	34.70	4.87	39.71
L79-1002 ec	GA	4.65	75.20	42.75	32.45	36.88	5.87	41.26
N-51 eg	EP	6.78	77.06	52.34	24.72	44.60	7.47	41.49
PI 300086 eg	EP	6.28	74.53	46.82	27.72	39.88	6.94	43.02
L79-1002 ec	EP	4.98	68.38	45.67	22.71	37.93	7.74	39.13
S-41 eg	EP	6.45	73.51	51.19	22.32	41.04	9.15	34.42
Hexaploid X2 eg	EP	8.60	74.03	49.57	24.46	41.00	8.60	39.75
PI 300086 X Mott eg	EP	7.71	71.52	47.30	24.22	39.41	7.90	44.32
US72-1153 ec	EP	(5.64)‡	73.95	44.46	29.48	38.99	5.47	69.41
124-A-6 seeded eg	EP	7.01	75.87	50.66	25.21	41.35	9.32	60.92
US 56-9 ec	ML	5.34	67.69	44.47	23.22	36.78	7.70	48.48
US 78-1009 sc	ML	4.19	62.79	41.21	21.58	33.89	7.31	49.39
CP72-1210 sc	ML	4.95	58.73	38.78	19.95	32.42	6.36	42.10
L79-1002 ec	ML	3.59	74.05	50.10	23.95	42.09	8.01	45.50
US 72-1153 ec	ML	4.16	69.96	45.45	24.51	38.78	6.66	45.36
1K 7647 er	ML	4.95	69.30	45.44	23.86	39.14	6.29	45.66
N-51 eg	ML	4.50	73.63	48.72	24.91	41.64	7.08	64.52
US 67-2022 sc	ML	4.44	42.33	26.30	16.03	22.56	3.73	69.83

† eg = elephantgrass, sc = sugarcane, ec = energycane, and er = erianthus.

‡ Missing data--IFAS lab data used.

* Location: GA was Green Acres Agronomy Farm near Gainesville, FL; EP was Energy Park on University of Florida campus at Gainesville, FL; and ML was on phosphatic clay at Mined Lands Agricultural Research/Demonstration Project headquarters in Polk County, FL.

** CP = crude protein, NDF = neutral detergent fiber, ADF = acid detergent fiber, H-CELL = hemicellulose estimated by subtracting ADF from NDF, CELL = cellulose, LIG = lignin, and IVDMD = *In vitro* digestible dry matter.

Table 5. Chemical composition of selected tall grass biomass crops grown at several locations in Florida in 1993 growing season.

Entry*	Location†	Chemical composition‡					
		CP‡	NDF	ADF	H-CELL	CELL	LIG
		%					
N51 eg	GA	7.44	74.55	44.68	29.87	38.11	6.31
L 79-1002 ec	GA	8.20	75.25	42.99	32.26	35.51	5.63
PI 300086 eg	GA	8.78	77.99	45.70	32.29	39.24	6.73
US 72-1153 ec	EP	6.85	72.67	43.58	29.09	37.94	5.77
N51 eg	EP	6.62	77.12	46.39	30.73	37.85	6.37
L 79-1002 ec	EP	7.46	73.67	43.10	30.57	34.93	5.83
PI 300086 eg	EP	7.66	78.47	47.44	31.03	38.48	7.75
US 72-1153 ec	ML	3.85	73.81	45.60	28.21	39.28	6.49
N5I eg	ML	4.49	78.04	58.10	19.94	47.18	9.63
IK-7647 er	ML	4.37	80.13	50.72	29.41	42.48	8.12
US 56-9 ec	ML	4.27	72.30	45.53	26.77	36.70	6.94
L79-1002 ec	ML	4.23	76.45	46.32	30.13	38.88	7.17
US 67-2022 sc	ML	5.19	64.39	38.54	25.85	31.66	5.05
CP 72-1210 sc	ML	4.41	66.13	39.88	26.25	33.61	5.40
US 78-1009 sc	ML	4.18	70.15	39.92	30.13	34.11	5.99
US 67-2002 sc	ML	4.44	58.03	34.89	23.14	29.71	5.30
Temperate corn st	ML	7.87	82.32	45.15	37.17	39.65	6.24
Tropical corn st	ML	8.70	75.34	41.03	34.31	36.62	5.54

† Location: GA was Green Acres Agronomy Farm near Gainesville, FL; EP was Energy Park on University of Florida campus at Gainesville, FL; and ML was on phosphatic clay at Mined Lands Agricultural Research/Demonstration Project headquarters in Polk County, FL.

‡ CP = crude protein, NDF = neutral detergent fiber, ADF = acid detergent fiber, H-CELL = hemicellulose estimated by subtracting ADF from NDF, CELL = cellulose, LIG = lignin, and IVDMD = *In vitro* digestible dry matter.

* ec = energy cane, sc = sugarcane, er = erianthus, eg = elephantgrass and st = stover.

Table 6. Average chemical composition of oven dry biomass from the various tall grass crops over genotypes, locations and 1992 and 1993 growing seasons.†

Tall grass crop	No. of samples	Chemical composition						
		CP	NDF	ADF	H-CELL	CELL	LIG	IVDMD
		%						
Elephantgrass	13	6.90	74.59	46.68	27.95	39.47	7.06	44.36(8)‡
Erianthus	2	4.73	74.72	48.08	26.64	40.81	7.20	45.66(1)
Energycane	12	5.27	72.78	45.00	27.78	37.64	6.60	49.52(6)
Sugarcane	6	4.56	60.75	37.44	23.31	31.84	5.64	53.77(3)

† This table summarizes data reported in Tables 4 and 5.

‡ No. of samples in parenthesis when less than total number of samples for crop.

ENERGY, ECONOMIC, AND ENVIRONMENTAL IMPLICATIONS OF PRODUCTION OF GRASSES AS BIOMASS FEEDSTOCKS

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Perennial prairie grasses offer many advantages to the developing biofuels industry. High yielding varieties of native prairie grasses such as switchgrass, which combine lower levels of nutrient demand, diverse geographical growing range, high net energy yields and high soil and water conservation potential indicate that these grasses could and should supplement annual row crops such as corn in developing alternative fuels markets. Favorable net energy returns, increased soil erosion prevention, and a geographically diverse land base that can incorporate energy grasses into conventional farm practices will provide direct benefits to local and regional farm economies and lead to accelerated commercialization of conversion technologies. Displacement of row crops with perennial grasses will have major agricultural, economic, sociologic and cross-market implications. Thus, perennial grass production for biofuels offers significant economic advantages to a national energy strategy which considers both agricultural and environmental issues.

Introduction

This paper will have four general parts. These include 1) U.S. energy markets and the niche which biofuels may fill, 2) the contribution to agriculture and scope of current agricultural production, 3) the role of technology in reducing barriers to market feasibility and 4) the significance of environmental issues. Crucial to understanding each of these four parts is in evaluating relationships among them and integration of these in any discussion of the potential for lignocellulosic inputs to the production of ethanol or other fuels produced by lignocellulosics. This is the reason for complexity and potential misunderstanding of any eventual benefits which may be derived from production of liquid fuels from renewable biomass sources. First, an understanding of the United States energy situation and opportunity for production of ethanol from lignocellulosic crops will be outlined. Second, agriculture, and more specifically, corn grain to ethanol in the U.S. is heavily subsidized and there are many incentives to produce traditional and conventional agricultural crops as a result. Economically, production and market incentives are strong. The technological development and advanced engineering is very capable of producing vast quantities of ethanol at a low price in a fixed market. Last, specific and significant environmental issues have recently have come to the forefront of the energy crop production debate. Environmental concerns have been voiced with respect to current agricultural production, but not with the intense scrutiny as potential alternative energy crops are.

After screening numerous annual and perennial species (Wright et al., 1994), the reduced cultivation, generally lower nutrient demand, and positive environmental attributes of the native American prairie grass, switchgrass, has led to its selection as a model herbaceous energy crop by the Department of Energy's (DOE) Biofuels Feedstock Development Program (BFDP) (McLaughlin, 1992). Research completed on this species to date, suggests that it could provide significant future ecological and economic advantages as well over annual crops such as corn. The energy, agricultural and agronomic, economic and environmental rationale for considering switchgrass as an alternative to corn is now presented.

Energy Situation in the United States

Transportation fuels in this country have been dominated by oil for nearly 100 years. Oil fossil fuels are neither endless in supply nor environmentally benign. Energy price shocks have proven costly as measured by the extent of their dislocative effects. While the time frame is uncertain, alternative fuels will need to be developed to replace current transportation fuels. A longer term perspective is important in developing bioenergy systems. Most current development in this area has been catalyzed by environmental mandates from the United States Environmental Protection Agency (USEPA). Development has also been attributed to economic factors in oil markets as a result of supply and demand shocks.

Fuel cell technology and methanol for internal combustion engines are two potential alternatives to gasoline. Fuel cells which generate electricity from fuels such as hydrogen and methanol are still being developed. Energy costs from fuel cells is currently seen as being greater than gasoline per unit of energy. If these fuels cells are operated from methanol, methanol is considered to further the greenhouse effect. If operated on hydrogen, remote generation of hydrogen would be necessary. Methanol to operate internal combustion engines is less expensive than gasoline, but must be produced from natural gas. This is seen to contribute nothing to reducing the greenhouse effect (Foody, 1988).

Ethanol is another alternative to fossil fuels for powering internal combustion engines and is the focus of this paper. Ethanol can be used as a blended fuel at 10 percent with 90 percent gasoline, or as a neat fuel (100 percent ethanol). It is currently used to enhance octane levels in gasoline, and acts as a co-solvent for other fuel additives. Its ability to substitute for other additives with harmful emissions may eventually add economic value above and beyond simply being an additive to gasoline.

The increased use of renewable fuels for energy offers the United States a strategy for significantly reducing national dependency on imported oil (Lynd et al., 1991; Robertson and Shapouri, 1993). There are several renewable feedstocks that can be used to produce ethanol, while providing diverse benefits to the national agricultural economy. Sugar, grain, and lignocellulosic biomass such as wood, agricultural residues, herbaceous crops such as sorghum, and switchgrass, and municipal wastes and paper are the most prevalent.

Current production of ethanol stands at 1426.5 million gallons in the United States. 1235 million gallons is produced from corn, the remaining from other sources (Gists-brocades, 1995). Projections for future supply and economic gain are derived based largely on the use of corn as the feedstock (Petrulis et al., 1992).

Net Energy Projections

The capacity of energy crops to offset imported energy will depend on the net energy return achieved in the series of energy consuming processes by which crops are grown, harvested and converted to energy. Extensive studies to date support the conversion efficiency of nearly 5:1 (units of energy out per unit in). Switchgrass requires less energy to produce than does corn. Corn produced per acre of land contains 50 million BTUs and requires 7.6 million BTUs to produce for an energy out-energy in ratio of 6.67.

Inclusion of corn stover improves the energy efficiency ratio to 8.8. An acre of switchgrass will produce 20.6 times the energy required to produce it if it is transported directly to the ethanol plant. The higher ratios for switchgrass result largely from the perennial nature of switchgrass (remaining in production for 10 years or more before replanting) and from lower chemical and fertilizer requirements. Chemical and fertilizer application for production were obtained from USDA (1991) and from The Fertilizer Institute (1988; 1992), DeLuchi (1991), and Pimental (1980). Transportation energetics were derived from Fluck (1992). Identical equipment complement assumptions were made for corn and switchgrass for preparation and planting; harvesting and handling equipment obviously varied (Fluck, 1985; and Bowers (1992)).

While net energy returns will vary somewhat regionally the energy advantage of grasses has been found to be consistently and significantly higher than for corn in all regions considered. The overall implication of the major portion of the differences among geographic production regions appears to stem from a net energy savings per unit of land used for perennial grasses as compared to corn.

Agricultural Benefit and Agronomic Potential

Perennial grasses were an ecological cornerstone of the early American prairie because of their forage quality and soil stabilizing attributes (Weaver, 1968). To date switchgrass has been bred primarily to enhance its nutritional value as a forage crop for livestock (Vogel, 1989). It has been managed primarily as a hay crop and early yields (4-17 metric tons per hectare (MTH)) have averaged approximately 60% above nation-wide yields for the 60 million acres of hay harvested annually in the United States (USDA, 1991). Recent research with several switchgrass varieties within the Department of Energy herbaceous crop research program (McLaughlin, 1992) is focusing more on total biomass production rather than foliage composition. This research and the evaluation of better adapted varieties has resulted in yields on research plots in Alabama as high as 35 MTH (Sladden et al., 1991) in a single year and 24 MTH over 5 years. During the latest test cycle yields have averaged approximately approximately 11 MTH across 17 locations in the Midwest and Southeastern United States for still aggrading 2 year old stands. These yields are being produced without irrigation, without the annual cultivation and planting cycle of annual crops, and with nitrogen and phosphorous fertilizer requirements that are typically one-fourth to one-half those for corn production. New breeding activities that are underway in the DOE sponsored BFDP are emphasizing increased total biomass production, and leaf nutrient contents. Some components such as nitrogen and potassium, may reduce biomass conversion efficiency. We estimate that 11-22 $MTHy^{-1}$ could be achieved with current varieties and production techniques in better switchgrass growing regions.

Economics

The Biofuels Feedstock Development Program staff and economists at Oak Ridge National Laboratory, and others, have extensively studied and researched the economics of switchgrass production and potential in the United States. These crop production budgets are being empirically verified now as the USDOE begins to fund large scale plantings of switchgrass for energy. Expansion of ethanol production from a current 0.8 billion gallon level to a level that will significantly offset dependency on foreign oil imports is anticipated to result in increased agricultural productivity, the creation of additional income for farmers, and thus implications for production of several types of crops. Based on the assumption that increased production will be achieved through increased utilization of corn, the United States Department of Agriculture's Economic Research Service (ERS) estimated agricultural impacts for two scenarios: an increase to 2 billion gallons by 1995, and 2) an increase to 5 billion gallons by 2000 (House et al., 1993). In the first scenario corn acreage is increased by 2.6 million acres and net farm income is increased by $153 million; in the second, acreage is increased by 9.3 million and net farm income increased by $1.6 billion. Significant effects on other crops and activities are not achieved until the second scenario, which is projected to result in a loss of $550. million in livestock production, because of increased feed costs associated with competition for corn as a biofuel.

Examination of the demographics of production, gain, and loss reveal some important regional discrepancies when additional bioenergy needs are met solely with corn. The net economic gain will be realized primarily in the current Corn Belt, Lake and Plain States that are already in primary corn producers. Cattle production losses will be spread more evenly across all cattle producing states. Thus, in spite of a national agricultural gain, the southeastern and mid-Atlantic states will experience a net economic loss which will be augmented by a loss of approximately 700,000 acres of soybean and cotton acreage associated with grain production shifts under increased corn production.

By contrast, a shift to reliance on perennial grass production could be effected using a much broader spectrum of land quality types, thereby impacting other crops minimally and spreading the benefits more evenly across the country. The southern states, which currently have a depressed agricultural economy, have provided the highest yields of warm season perennial grasses thus far, and would be among the most suitable target areas for biofuels industries.

Economic Factors Affecting Commercial Feasibility

Foody (1988) suggested that the technology for producing ethanol from biomass was improving rapidly and that laboratory reports were approaching the ultimate levels of techno-economic feasibility. Neat ethanol could compete in the current marketplace with gasoline at a price of $20. to $30. per barrel of oil. A successful demonstration of cost effective ethanol production would dramatically change the debate over major environmental problems that are energy related. Fuel ethanol's primary advantage is environmental as it is much cleaner burning than gasoline. When derived from lignocellulosic biomass, it is the only liquid transportation fuel that does not contribute to the greenhouse effect (Foody, 1988).

There are many additional factors that will affect the commercial feasibility. The ability to successfully develop enzymatic hydrolysis technology will be crucial. The process for making ethanol from lignocellulosic biomass involves seven major steps. Although complete treatment of each of these steps is beyond the scope of this paper, (see Foody 1988) they are biomass production, pretreatment, enzyme production, enzymatic hydrolysis, fermentation, distillation and by-product processing. Since each of these processes are interdependent, improving one may decrease the ability to make improvements in another. Finally, the ability to market by-products and co-products is crucial to the economic viability of any commercial system (ICAST, 1994).

Conservation Reserve Program

The Conservation Reserve Program (CRP) was initiated by the United States Department of Agriculture's (USDA) Soil Conservation Service (SCS) in 1985 largely to stabilize and improve soils degraded by over cropping. Over 36 million acres of land were idled by this law, primarily in the Great Plains and Southeast. Much of this land was replanted to perennial grasses, that had formed the principal species of the original American prairie. Predominant species were big bluestem, Indian grass, wheatgrass, and a particularly hardy and widely adapted and desirable species with potential energy use, switchgrass (*Panicum virgatum*).

The CRP program is at a critical point after 10 years of contracting with agricultural producers. Renewal or elimination options are currently being considered in the 1995 Farm Bill. Critics see the CRP as an unnecessary expense with questionable benefits to taxpayers. Recent consideration of both the resource conservation benefits of CRP and economic subsidy costs of returning these lands to annual row cropping suggests that CRP represents a gain to taxpayers (Kruse, 1994). Recent studies suggest that failure to renew the CRP will result in a rapid return of much of this land to annual row crops, notably wheat with significant downward pressure on existing wheat prices. An alternative to returning CRP to the same practices that necessitated its implementation initially, is to consider these lands for energy crops that can both preserve and enhance land quality and provide an economic return to the landowners. This possibility is strengthened by realizing that native perennial grasses that were planted under the CRP, are also excellent choices for production of transportation fuels.

Environmental Considerations

Soil conservation and augmentation is an important benefit from growing perennial grasses. The CRP has considered soil stabilizing properties and perennial grasses provide excellent protective cover and nutritive value to wildlife. Perennial grasses most obvious advantage over row crops such as corn is very significant reduction in soil erosion. Soil loss from erodable crop land can be staggering and results in loss of valuable nutrients from that land. One significant consequence is sedimentation and chemical input to and of adjoining areas and wetlands.

Contrast in erosion rates between continuous cultivation as row crops such as corn and perennial grasses such as switchgrass at many locations indicate that annual soil loss is accelerated typically 100-2500 times by continuous annual crop production (Shiflet and Darby, 1985). During heavy rains erosion differences can be even more marked.

Losses in soil organic matter are also increased by annual cultivation due to increase soil organic matter turnover as well as increased transport of topsoil (Buckman and Brady, 1960). The current rate of loss of soil organic matter (SOM) through annual row cropping practices in the United States has been estimated to be 2.7 million metric tons per year (CAST, 1992). This loss is important not only because it represents 7.5% of the total carbon released to the atmosphere by combustion of fossil fuels, but because SOM is critical to productive soils. Soil moisture holding capacity, soil density and aeration, and soil nutrient availability and conservation are among the essential properties controlled by SOM (Anderson and Coleman, 1985).

Recent studies of the changes in soil organic matter during 5 years of perennial grass production on CRP lands indicate that perennial grasses added 1.1 tons of carbon / ha^{-1} / yr^{-1} to the upper 100 cm of CRP soils (Gebhardt, 1994). These additions replaced 23% of the soil carbon lost during decades of prior tillage. The large standing pools of roots, which can equal or exceed annual above ground production (Anderson and Coleman, 1985), and the rapid turnover of these pools, are the source of this carbon. Preliminary data from soils where switchgrass is being examined for energy production (Bransby et al.,

1994) indicate that below ground root mass is very high totaling almost 8 MTH in just the top 75 cm. With Alamo switchgrass, over 1 MTH was found just in the interval 60-75 cm.

Summary

Perennial grass production for biofuels offers significant advantages to a national energy strategy which considers both environmental and economic issues. The benefits of using a native prairie species such as switchgrass to meet increasing an energy demand include improved soil quality, reduced soil erosion and associated pollution of aquatic systems, reduced emissions of greenhouse gases, increased efficiency of land and energy use, and a more equitable distribution of economic benefit to farmer-producers. To achieve these benefits in a timely manner will require we look beyond the relatively short term supplies of supply of municipal waste and crop and other residues to industrial feedstocks for future needs; crops grown specifically for a dedicated energy end-use.

Our planning should include accelerated commercialization of both ethanol conversion and grass fired combustion systems. It should also study the options for maintaining landowner participation in a conservation reserve program for which conservation objectives could be maintained by reduced subsidies and for involvement of landowners in energy crop production. The benefits to the national economy and national environment of such strategies appear too obvious to ignore.

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RESPONSE OF 'ALAMO' SWITCHGRASS (*Panicum virgatum*) TO WEED MANAGEMENT PRACTICES

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Abstract

Field studies were conducted in 1992 and 1994 to evaluate herbicides that would provide weed control and biomass yield of 'Alamo' switchgrass during the year of establishment. For grass weed control, bensulide was applied preplant incorporated (PPI) at 4.4 kg ai ha^{-1}, while MSMA was applied postemergence over the top (POST) at 2.2 kg ai ha^{-1} to switchgrass that had two to four leaves. Herbicides applied POST for control of broadleaf weed species included 2,4-D at 0.6 kg ai ha^{-1} or metsulfuron at 0.02 kg ai ha^{-1}. Herbicide treatments included bensulide and MSMA applied alone or in combination with 2,4-D or metsulfuron. They were arranged in a randomized complete block design and replicated four times. Weed control, crop tolerance and yield data were taken over time. Bensulide or MSMA applied alone provided 80% or greater control of large crabgrass, broadleaf signalgrass and fall panicum for the two years. The addition of metsulfuron or 2,4-D provided acceptable control of smooth pigweed, prickly sida, pitted morningglory and sicklepod. MSMA treatments produced slight PANVI injury that ranged from 20 to 36%. Bensulide injury was mostly moderate ranging from 19 to 88%. Although less injury was recorded with MSMA treatments, bensulide treatments trended higher for establishment-year biomass production that averaged 5123 kg ha^{-1} as compared to 4239 kg ha^{-1} for MSMA treatments. Nomenclature: bensulide, *0,0*,-bis(1-methylethyl)*S*-[2-[(phenylsulfonyl)amino]ethyl] phosphorodithioate; metsulfuron, 2-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]amino]sulfonyl]benzoic acid; MSMA, monosodium salt of methylarsonic acid; 2,4-D, (2,4-dichlorophenoxy) acetic acid; broadleaf signalgrass, *Brachiaria platyphylla* (Griseb.) Nash, BRAPP; large crabgrass, *Digitaria sanguinalis* (L.) Scop., DIGSA; fall panicum, *Panicum dichotomiflorum* Michx., PANDI); switchgrass, *Panicum virgatum* L. 'Alamo', PANVI; smooth pigweed, *Amaranthus hybridus* L., AMACH; prickly sida, *Sida spinosa* L., SIDSP; pitted morningglory, *Ipomoea lacunosa* L., IPOLA; sicklepod, *Cassia obtusifolia* L., CASOB.

Introduction

Switchgrass has been described as an energy crop that is compatible with existing farming systems of the Southeast. When comparing yields of switchgrass across states, the 'Alamo' cultivar of switchgrass yielded at least 50% higher in Alabama (Martin, 1992). This increased yield could be associated with the longer growing season of the Southeast and that the 'Alamo' cultivar often breaks dormancy 4 to 6 weeks before other cultivars which enables utilization of the lengthened growing season (Bransby, 1993). With yields of eight varieties of switchgrass in Alabama compared, 'Alamo' and 'Kanlow', lowland ecotypes, produced 17.5 and 13.8 MG ha^{-1}, respectively, during the year of establishment as compared to an average 8.6 MG ha^{-1} for upland varieties (Sladden, 1991). The second year total yields increased 98% for 'Alamo' and 68% for 'Kanlow' (Sladden, 1991).

Because switchgrass has poor seedling vigor, adequate weed control needs to be established as early as possible to relieve weed competition. Switchgrass stands during the establishment year were reduced to 61% stand from large crabgrass competition (Bryan, 1968). Also plants at midsummer, within weedy plots were smaller and less robust when compared to weed-free plots and total season biomass yields were greater for weed-free plots (Bryan, 1968). Bovey (1979) concluded kleingrass (*Panicum coloratum* L.) establishment was difficult in weedy conditions because seedling growth was often slow and that seedlings competed poorly with other vegetation. With good weed control at 60 to 90 days after planting, good establishment of kleingrass was obtainable (Bovey, 1979). Also noted, warm-season grasses were more vulnerable to weed competition in the seeding year because they are slow to establish a dense sod (Bryan, 1968).

McCarty (1976) reported that acceptable stands of 'Pathfinder' switchgrass were only obtained with herbicide or weed-free treatments. Martin (1982) obtained no harvestable switchgrass yield without weed control.

'Alamo' switchgrass, in a greenhouse study, was tolerant to bensulide, MSMA and metsulfuron but was injured by triazines, 2,4-D, and siduron (Bovey, 1991).

Postemergence application of atrazine at 1 to 3 weeks, in both greenhouse and field studies, showed potential in 'Pathfinder' switchgrass as a herbicide to relieve weed pressure (Bahler, 1990). Increased seedling vigor of switchgrass was obtained with weed control using atrazine and propazine (Peters, 1975). From a field study, Bahler (1984) concluded that 'Pathfinder' switchgrass was tolerant to preemergence applications of atrazine at a rate of 2.2 kg ha^{-1}. Although, atrazine can be used on some switchgrass cultivars, it does not provide acceptable control of large crabgrass, fall panicum or broadleaf signalgrass (Thompson, 1971). However, McKenna (1991) reported unacceptable injury to 'Pathfinder' switchgrass with treatments of atrazine.

Switchgrass forage yield and stand frequencies were improved with sulfonylurea herbicides (sulfometuron, chlorsulfuron, and metsulfuron) (Peters, 1989). In addition, Peters (1985) reported greater forage yields of 'Pathfinder' switchgrass in both the establishment year and established plots with postemergence application of sulfometuron.

The objective of these studies was to identify herbicides that would provide acceptable grass and broadleaf weed control, with sufficient 'Alamo' switchgrass tolerance, that a significant dry matter yield could be obtained during the year of establishment.

Materials and Methods

Small-plot replicated field studies were conducted in 1992 and 1994 using herbicides identified from greenhouse studies that 'Alamo' switchgrass had shown tolerance to. The studies were conducted at the Plant Breeding Unit of the E. V. Smith Research Center in central Alabama on a Wickham fine sandy loam soil. Soil pH was 6.2 and P and K soil-test levels were high. Nitrogen was applied at planting at a rate of 67 kg ha^{-1} N. Plot sizes for 1992 were 3 by 9 m with four replications, and sizes for 1994 were 2 by 6 m with four replications. Herbicides included bensulide, MSMA, 2,4-D and metsulfuron. The first two were chosen for their efficacy against grass weeds while the latter two are more efficacious against broadleaf species. Bensulide was applied PPI at 4.48 kg ai ha^{-1} and was evaluated alone or with a sequential of 2,4-D (0.56 kg ai ha^{-1}) or metsulfuron (0.02 kg ai ha^{-1}). Bensulide was soil incorporated in 1992 with a vertical-action tiller that tilled to a depth of 10 cm. Soil incorporation in 1994 was with a horizontal-action tiller that tilled to a depth of 12 cm. MSMA (2.24 kg ai ha^{-1}) was applied POST to switchgrass with two or four leaves. MSMA was applied alone or in admixture with 2,4-D or metsulfuron at the above rates. The seeding rate was 17 kg ha^{-1} at a planting depth of 1 cm with 53 cm rows in 1992, but in 1994 seeds were broadcasted. Weed control and PANVI injury were taken over time. PANVI injury ratings were assigned a zero when a stand was uniform in density and size. Ratings from 1 through 30 constituted slight injury; ratings of 31 through 60 moderate injury; ratings of 61 through 99 indicated severe injury. Biomass data were collected prior to frost. No data were available for the 1993 season due to crop failure which resulted from switchgrass seeds that germinated only 19%.

Biomass yield data for the study established in 1992 were taken in 1993 and 1994. This experiment received a blanket application of atrazine + paraquat, (2.24 + 0.56 kg ha^{-1}) in late March of 1993 and 1994. Nitrogen was applied at 67 kg ha^{-1} N in April and again in July after the first harvest. The second harvest occurred the last week in October to first week in November.

Data were analyzed for analysis of variance. Bensulide and MSMA treatments along with metsulfuron and/or 2,4-D and non-treated plots were the treatments utilized. Means separation was obtained through Duncan's multiple range test (P=0.05).

Results and Discussion

PANVI injury in the 1992 study was generally acceptable, ranging from 30 to 49%, with herbicide combinations that provided 80% or greater control of both grass and broadleaf weeds. Failure to control any weeds (non-treated) resulted in 97% PANVI injury. Bensulide applied alone, which failed to control IPOLA and SIDSP, resulted in 88% injury to PANVI. Although the treatments containing MSMA plus 2,4-D and metsulfuron showed slightly less PANVI injury and equal weed control, bensulide followed by metsulfuron showed a trend for higher biomass yield the first year. First-year yields were not taken for bensulide alone or the non-treated because of extensive weed contamination, Table 1.

Biomass production for 1993 was lower where weed control was marginal or non-existent during the establishment year of 1992. The bensulide/metsulfuron treatment produced almost twice the dry matter as the non-treated, which shows a residual effect from lack of weed control during the year of establishment. Dry matter yields for 1994 were comparable among all treatments. Cumulative dry matter production for the bensulide/metsulfuron treatment over the 3 years was 42,418 kg ha $^{-1}$ while the non-treated yielded 27,958 kg ha^{-1} over the same period, Table 2.

PANVI injury for the 1994 study was generally acceptable for all treatments, ranging from 19 to 59%. Highest PANVI injury occurred with the bensulide alone treatment, which failed to control IPOLA, SIDSP, and CASOB. Bensulide followed by either metsulfuron or 2,4-D produced excellent weed control while the MSMA combinations produced good weed control. PANVI biomass yield was comparable among all treatments but those receiving bensulide showed a trend for higher biomass yield the first year, Table 3.

Conclusions

Herbicide combinations were identified that provided acceptable control of common grass and broadleaf weeds found in the Southeast and acceptable 'Alamo' switchgrass tolerance. Although PANVI was generally more tolerant to MSMA, trends toward higher yields were evident with the bensulide combination treatments over the two years. This may be attributed to bensulide being applied at seeding which resulted in reduction in weed competition earlier during the more vulnerable germination and establishment period. However, this probably increased PANVI injury ratings. Bensulide applied PPI followed by a sequential POST of metsulfuron was the treatment of choice. However, these results apply only to 'Alamo' switchgrass since other cultivars may differ in response. For example, 'Alamo' is tolerant to MSMA but intolerance to this herbicide has been observed with 'Cave-In-Rock'. Likewise, 'Pathfinder' has been reported tolerant to atrazine applied at seeding, but the authors have observed severe injury to 'Alamo' from atrazine applied at planting.

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Table 1. PANVI Injury and Weed Control as Affected by Herbicide Combinations at Tallassee, 1992[a].

Herbicide Combinations	PANVI Injury	DIGSA Control	IPOLA Control	SIDSP Control	AMACH Control
			%		
Bensulide, PPI	88a	90a	28c	15c	95a
Bensulide, PPI Metsulfuron, 2LF	49c	81a	93a	96a	98a
Bensulide, PPI 2,4-D, 2LF	68b	86a	82a	48b	96b
MSMA, 2LF 2,4-D, 2LF MSMA, 4LF Metsulfuron, 4LF	30d	91a	96a	86a	98a
MSMA, 2LF Metsulfuron, 2LF MSMA, 4LF 2,4-D, 4LF	36cd	80a	96a	97a	98a
Non-Treated	97a	0b	0d	0c	0c

[a]Means followed by the same lower-case letter are not significantly different according to Duncan's multiple range test($P \geq 0.05$).

Table 2. PANVI Biomass as Affected by Herbicide Combinations at Tallassee, 1992[a].

Herbicide Combinations	PANVI Biomass[b] 1992	1993	1994
		kg ha^{-1}	
Bensulide, PPI	0b	10802bc	20317a
Bensulide, PPI Metsulfuron, 2LF	5084a	15119a	22215a
Bensulide, PPI 2,4-D, 2LF	2889a	12171ab	23436a
MSMA, 2LF 2,4-D, 2LF MSMA, 4LF Metsulfuron, 4LF	3481a	12667ab	22624a
MSMA, 2LF Metsulfuron, 2LF MSMA, 4LF 2,4-D, 4LF	2816a	12712ab	20395a
Non-Treated	0b	8638c	19320a

[a]Means followed by the same lower-case letter are not significantly different according to Duncan's multiple range test($P \geq 0.05$).
[b]Herbicide combinations apply only to 1992; entire experiment was treated with atrazine + paraquat in 1993 and 1994.

Table 3. PANVI Injury, Weed Control, and PANVI Biomass as Affected by Herbicide Combinations at Tallassee, 1992[a].

Herbicide Combinations	PANVI Injury	PANDI	DIGSA	IPOLA Control	SIDSP	CASOB	Dry Matter
				%			kg ha^{-1}
Bensulide, PPI	59a	83a	85ab	0b	15c	25c	6216a
Bensulide, PPI Metsulfuron, 3LF	31b	87a	90a	89a	99a	89a	5432a
Bensulide, PPI 2,4-D, 3LF	19b	90a	90a	94a	97a	91a	5992a
MSMA, 3LF	20b	81a	75b	74a	61b	66b	4984a
MSMA, 3LF Metsulfuron, 3LF	28bd	70a	78b	84a	99a	94a	4872a
MSMA, 3LF 2,4-D, 3LF	33b	68a	80ab	72a	96a	91a	5040a

[a]Means followed by the same lower-case letter are not significantly different according to Duncan's multiple range test($P \geq 0.05$).

SWITCHGRASS AS A BIOFUELS FEEDSTOCK FOR THE UPPER SOUTHEAST

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Abstract

Switchgrass (Panicum virgatum) has been identified as a promising perennial, herbaceous biofuels feedstock species. It is highly productive, even on marginal sites; but relatively little is known about its management as a potential biofuels feedstock. We no-till planted four varieties (Alamo, Cave-in-Rock, Kanlow, and Shelter) and two breeder's lines (NC1 and NC2) of switchgrass in 1992 and 1993 at eight locations across the upper Southeast (three sites in Virginia, two in Tennessee, and one each in Kentucky, North Carolina, and West Virginia). The plots were fertilized with 100 kg N/ha/yr, and P and K were maintained at high levels based on soil tests. Biomass was harvested once (in late Fall) or twice (in mid-Summer and again in late Fall) per year. The yield data presented here are from the most recent full season (1994).

Alamo and Kanlow were among the more productive varieties, averaging 14.3 Mg dry matter per ha across the eight sites and two cutting managements. One site averaged over 20 Mg/ha across varieties and cutting managements. When averaged across all varieties and locations, the two-cut system provided higher yields (15.0 Mg/ha) than a single harvest (11.7 Mg/ha). Shelter and Cave-in-Rock showed a 40% to 50% increase in seasonal total yield when cut twice rather than once, but other varieties and lines responded somewhat less to multiple harvests.

Taken together, these data suggest that switchgrass has good potential as a dedicated biofuels feedstock crop in the upper Southeast. The yield differences between genotypes point to potential improvements in productivity, especially if selection is made for biomass production (and not for forage quality). The yield advantage of multiple harvests over a single harvest needs further study to establish whether the higher levels of productivity can be maintained and whether the additional harvests are economic.

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Introduction

Switchgrass is a tall-growing, perennial bunchgrass that is native to North America. It has value for forage, soil conservation, and wildlife habitat; and it is known for its wide adaptability, drought tolerance, and high yields with relatively low inputs. Because of these traits, it has been identified as a promising biofuels feedstock candidate that might someday be grown as a dedicated fuelcrop on a large scale (McLaughlin et al., 1994). While switchgrass has been studied as a forage, little work has been done from a fuelcropping perspective. Its management as an energy crop requires closer scrutiny. Our experience and that of others suggests that more information is needed on several aspects of switchgrass management and biology before it can be widely adopted as a fuelcrop.

Recent DOE-sponsored work with switchgrass has revealed large yield differences between varieties (Sanderson et al., 1995). Productivity can vary by two- and three-fold between varieties within a location and growing season. No single variety appears to have a yield advantage across all locations, because location-specific factors (soil?, photoperiod?, other?) appear to interact with genotype in determining yield potential. But the nature of the interaction and, indeed, the main effects that determine yield potential are not well-established. In fact, even within a particular location, the variety of choice is not always clear. More information is needed.

The management of switchgrass harvests is also important. Frequency and timing of harvests will likely have agronomic and economic consequences (Vaughan et al., 1989). Will two harvests per season yield more biomass than one? Can they do so perennially? Is there enough yield benefit to justify economically a second harvest? We know of no work that addresses these questions systematically on a wide scale.

Materials and Methods

Four switchgrass varieties (Alamo, Cave-in-Rock, Kanlow, and Shelter) and two breeder's lines (NC1 and NC2 from Dr. David Timothy of North Carolina State University) were no-till planted (Wolf et al., 1989) in 2 m by 6 m plots at eight sites (Princeton, Kentucky; Raleigh, North Carolina; Jackson, Tennessee; Knoxville, Tennessee; Blacksburg, Virginia [two sites]; Orange, Virginia; and Morgantown, West Virginia) in 1992. The experimental layout at each site was a four-replication, randomized complete block design with each variety or line represented twice in a block. One plot from each variety or line was for harvest once (at the end of the season, after full senescence of above-ground parts), and the other was to be cut twice (at heading stage and again at the end of the season).

In most cases, the 1992 plantings were quite successful. However, one location (Princeton, KY) was entirely replanted in 1993, and selected plots were replanted at a few other sites also. By the 1994 season, the variations between and within sites in stage of establishment were considered to be minimal; so sites were managed essentially uniformly.

Nitrogen was applied at 100 kg/ha at the beginning of the season to all plots to be cut once and at 50 kg/ha to all plots to be cut twice. An additional 50 kg/ha of N was applied after the first harvest of the two-cut management treatments. Soil tests were taken, and K and P fertilizers were applied as needed to reach a high level of fertility based on recommendations from each geographic location.

In 1994, plots for each variety or line were harvested either once (in October or November, depending on location) or twice (in June or July and again in October or November). A subsample of the harvested material was dried at 70°C to determine moisture content, and yields from plots were extrapolated to Mg dry matter per ha. Data were subjected to analysis of variance, and least significant differences were determined for values obtained within each site.

Results and Discussion

When considered across the entire multistate study, yields were greatest from the Knoxville, TN, location and least from Orange, VA, and Princeton, KY (Table 1). In fact, the yields at Knoxville were twice those of the two lower-yielding locations. The low yields at the Orange, VA, location were probably due to an early-season drought. For the KY location, this was the first post-planting year of production, and that likely contributed to lower yields there.

When plots were harvested once at the end of the season, Alamo and Kanlow tended to have higher yields, and Cave-in-Rock and Shelter tended to have lower yields than the other varieties or lines; but varieties and lines varied considerably between sites in seasonal single-harvest yield rankings. This suggests that genetic differences are available for breeding for yield, but selection will perhaps need to be done on a restricted regional basis.

When biomass was cut twice during the season, four of the varieties averaged 15+ Mg/ha. Only Shelter and NC2 had lower yields. Between sites, rankings for two-cut productivity were again quite variable. For example, Shelter was the most productive variety when harvested twice at Knoxville, TN, our most productive site. It would appear that cutting management and management x site interaction must also be considered in future breeding and selection for biofuels varieties.

Harvesting twice during the season increased total yields by 28% over harvesting once when considering all locations and all varieties (Table 2). The Jackson, TN, and Princeton, KY, locations had the greatest benefit from two harvests, and the Morgantown, WV, location had the least benefit. In Morgantown, Alamo and Kanlow both showed a yield reduction with two harvests, but that did not occur at any of the other sites. At all locations, Cave-in-Rock and Shelter had a greater benefit (avg. 46%) due to two harvests than the other varieties or lines (avg. 23%). In general, first-harvest yields (except at the droughty Orange, VA site) of the two-cut management were higher than the last harvest.

The results from the cutting-management study suggest that two harvests per season can provide more biomass than a single cut made at the end of the season. The yield advantage perhaps is not large enough to be economical, however. Data from additional

Table 1. Yields of Six Varieties or Lines of Switchgrass in 1994 at Eight Locations across the Upper Southeast. Plots Were Harvested Once (in Fall) or Twice (in mid-Summer and again in Fall).

		Virginia			Tennessee					
Cutting Management	Variety/Line	B'burg (A)	B'burg (B)	Orange	Knox.	Jack.	NC	KY	WV[1]	Average
		Mg/ha								
Once	Alamo	10.5	9.7	12.2	20.3	11.0	13.8	9.6	15.4	12.8
	Kanlow	11.4	14.3	10.9	20.1	12.0	14.3	9.7	15.2	13.5
	Cave-in-Rock	10.5	10.9	6.7	16.3	9.5	9.3	8.6	11.8	10.4
	Shelter	11.0	11.4	5.9	14.4	8.8	7.4	7.6	9.9	9.6
	NC1	13.1	14.3	11.6	17.2	10.4	11.5	7.7	12.1[1]	12.2
	NC2	13.1	12.7	10.9	19.5	10.5	10.8	7.8	12.1[1]	12.2
	Average	11.6	12.1	9.7	18.0	10.4	11.2	8.5	12.8	11.7
Twice	Alamo	12.3	12.8	11.5	24.2	14.2	16.2	16.0	14.4	15.2
	Kanlow	13.6	16.2	11.1	22.5	16.3	16.5	15.9	14.4	15.8
	Cave-in-Rock	15.0	15.4	10.6	22.9	16.0	14.3	15.7	14.5	15.6
	Shelter	12.8	14.4	6.6	24.6	15.1	12.1	11.0	12.0	13.6
	NC1	13.8	18.5	13.7	20.0	16.3	16.1	9.2	14.4[1]	15.2
	NC2	13.6	12.7	12.1	20.8	15.6	14.9	11.7	13.2[1]	14.3
	Average	13.5	15.7	10.9	22.5	15.6	15.0	13.3	13.8	15.0
LSD* 0.05		2.0	1.2	1.6	2.6	2.5	2.4	1.4	0.7	

*LSD is for comparison of means for varieties within and between cutting managements.

[1]NC1 and NC2 were not present in WV; their WV yields were calculated as missing plots in order to compare across varieties.

Table 2. Yield Advantage of Two Harvests (versus One) for Six Varieties or Lines of Switchgrass in 1994 at Eight Locations across the Upper Southeast. Percentage Difference = (Two Cuts-One Cut)/One Cut.

		Virginia			Tennessee					
Comparison	Variety/Line	B'burg (A)	B'burg (B)	Orange	Knox.	Jack.	NC	KY	WV[1]	Average
		Mg/ha								
Difference	Alamo	1.8	3.1	-0.7	3.9	3.2	2.4	6.4	-1.0	2.4
	Kanlow	2.2	1.9	0.2	2.4	4.3	2.2	6.2	-0.8	2.3
(Two Cuts-	Cave-in-Rock	4.5	4.5	3.9	6.6	6.5	5.0	8.1	2.7	5.2
One Cut)	Shelter	1.8	3.0	0.7	10.5	6.3	4.7	3.4	2.1	4.0
	NC1	0.7	4.2	1.1	2.8	5.9	4.6	1.5	2.3[1]	3.0
	NC2	0.5	0.0	1.2	1.3	5.1	4.1	3.9	1.1[1]	2.1
	Average	1.9	3.6	1.2	4.5	5.2	3.8	5.1	1.0	3.3
		%								
Percentage	Alamo	17	32	-5	19	29	17	67	-6	19
Difference	Kanlow	19	13	2	12	36	15	64	-5	17
	Cave-in-Rock	43	41	58	40	68	53	94	23	50
	Shelter	16	26	12	73	72	63	45	21	42
	NC1	5	29	9	16	57	40	19	19[1]	24
	NC2	4	0	11	7	48	38	50	9[1]	17
	Average	16	30	12	25	50	34	58	8	28

[1]NC1 and NC2 were not present in WV; their WV yields were calculated as missing plots in order to compare across varieties.

growing seasons will help reveal if the two-cut advantage can be maintained or increased. Other studies we have done suggest that taking two cuts can result in reduced yields in the succeeding year, but the timing of the harvests may be the critical; harvests taken relatively late in the growing season appear to be detrimental to the stand, but mid-Summer harvests are not of concern.

Taken together, these data suggest that switchgrass has good potential in the upper Southeast when grown as a dedicated biofuels feedstock crop. Obvious genetic variation exists in its yield potential, and that variation appears to interact with site-specific factors. Two harvests of switchgrass increased yield in almost all situations, but more studies are needed on timing and economics of multiple harvests. The authors thank Oak Ridge National Laboratory, managed by Martin Marietta Energy Systems for their support of this work.

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CARBOHYDRATE BIOFUELS I: ROOTFUEL STUDIES IN MEXICO, BRAZIL, ZIMBABWE AND INDIA

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Abstract

"Rootfuel," made by drying the fast-growing starchy-cellulosic taproots of certain members of the family Cucurbitaceae, has been under investigation by us since 1985. Rootfuel can be quickly dried to a much lower level of moisture content than seasoned wood, and also unlike wood, it contains a very small amount of lignin. If it is dry and burned with good draft, it can be burned more slowly than wood with very little smoke production.

We studied rootfuel made from *Cucurbita foetidissima* roots in dry, deforested and well-populated rural lands of Mexico, Brazil, Zimbabwe and India under sponsorship of the Biomass Users Network, with funding from the Rockefeller Foundation. Our purpose was to evaluate rootfuel as a replacement for wood, dung and crop residues to improve indoor air quality for health reasons, and to take pressure off of the remaining trees. Acceptability has been uniformly high. Small test plots have been planted, and new rootfuel species have been identified and tested.

Introduction and Background

The Disappearance of Woodfuel in the Third World

The woodfuel-deficit regions of Africa, Asia and Latin America, mostly drylands, are home to more than half the world's population and the numbers of inhabitants are growing. As deforestation of the world continues simultaneously with population growth, the people with inadequate access to woodfuel will probably rise from 1.3 billion in 1980 to 2.7 billion by the year 2000 (Chege 1993). This worsening deficit of woodfuel has stimulated the development community to sponsor such interventions as woodfuel plantationing, improved woodstoves, gas stoves, and solar cookers. But local people usually turn to animal dung and crop residues as replacements for woodfuel when it becomes scarce.

The Shortcomings of Woodfuel and the Potential for Rootfuel

Woodfuel is becoming more difficult to find, but this is not a good reason to create more woodfuel plantations which will perpetuate the burning of wood, an undesirable fuel for the open fires that typify most Third World cooking. Wood burns rapidly, inefficiently, and produces large volumes of smoke containing polyaromatic hydrocarbons, carcinogens, irritants and respirable particulates that damage the health of the cooks, mostly women, as well as infants and small children present during the cooking process (Shultz et al. 1993).

Recently reported animal studies in *Science* magazine (Anon. 1995, 1771) conclude that woodsmoke constituents suppress the macrophages of the immune system so that respiratory pathogens cannot be readily defeated. The published literature on human health impacts of indoor smoke is voluminous and clear (WHO 1992). Globally, people exposed to woodsmoke are more likely to suffer respiratory diseases than those not exposed. Elderly women and small children are especially vulnerable. Woodfuel is usually replaced in deforested regions by dungcakes and crop residues, and these are also smokey fuels.

Better replacements are urgently needed. For obvious health reasons, successful candidates must produce little or no smoke, but there are many other criteria. Ideally, we believe that better fuels should meet a list of 20 criteria that we have organized into four major categories; Economic, Cultural, Production, and Utilization Criteria (Shultz and Bragg 1992). We emphasize relatively clean-burning non-woody carbohydrate biofuels produced by sun-drying the taproots of certain species of wild plants in the ubiquitous Cucurbitaceae family (gourds, melons, etc.). We call this unusual combustible "rootfuel," and it comes close to meeting our 20 criteria. If rootfuel or other nearly smokeless solid fuels are cultivated near home or sold at a reasonable price in a nearby marketplace this intervention may address as many as *seven* serious problems of the Third World (Shultz et al. 1993), including but certainly not limited to the health problems caused by smokey fuels.

Our first rootfuel study was published nine years ago (Shultz and Evans 1986). Since then, we have found that rootfuel is superior to wood in combustion properties and equal to it in other ways (Shultz et al. 1993). For example, Malkani has shown that a much lower weight of rootfuel, in comparison with woodfuel, is needed to carry out a given cooking task in a pot (Malkani 1988; Shultz et al. 1990). And carbohydrate biomass can be produced more rapidly than woody biomass in drylands.

Rootfuel Development Strategy: Women-Centered, Ethical, Participatory

To bring rootfuel to bear upon the many problems caused by burning woodfuel, dungcakes and crop residues, we advocate women-centered development strategies because of the strong gender bias involved in the woodfuel problem in the Third World. Women must not be excluded from processes at the local level of social learning of the optimum methods of production of rootfuel. They must be fully engaged in the planning and execution of rootfuel production and distribution schemes in their own communities. Women have a special concern for cooking-fuel acquisition, and rootfuel is primarily a women's technology (Shultz 1994). We have also written on ethically-based development strategies appropriate for rootfuel, using principles of self-reliance, sustainability, decentralization, and autochthonicity (Shultz et al. 1991; Bragg and Shultz 1992).

There is a great need for an inexpensive clean-burning biofuel in Latin America, Africa and Asia, and rootfuel may fill this market niche. Specific strategies need to be developed for development and production of rootfuel as a family crop, for small cooperative and individual businesses, both for rural and urban use. Examples of the latter are the replacement of urban charcoal utilization that is destroying the woodlands near the cities, and the replacement of urban woodfuel usage by the poor who are migrating to the cities.

Some rootfuel research and development can be centralized in laboratories or experiment stations, but we believe that most studies should be carried out locally, with participation by local people, especially women. Dried roots must be tested by local women for acceptability as cooking fuel, and local seed nurseries established for the successful candidates. Local root-production plots must be planted under supervision, to develop trustworthy yield estimates and to learn the best growing methods for maximum yields. Local people must participate in deciding how to organize production and distribution of rootfuel, with environmental and socio-economic sustainability.

Selection of Locations and Objectives for These Studies

This study included four locations: central and northern Mexico, northeast Brazil, central Zimbabwe, and southern and central India. The choices were based on the presence of large populations in relatively deforested dryland areas where fuel is in short supply, the known presence of wild dryland cucurbits with rootfuel potential, and the availability of indigenous support organizations to assist local people as they learn about and test rootfuel.

The dry north and central interior of Mexico is apparently the center of origin of *Cucurbita foetidissima*, our most successful rootfuel cucurbit to date. It grows widely in this region which is heavily deforested and desertified in many parts. The northeast of Brazil is highly populated, poverty-stricken, dry, and deforested. The dry Midlands of Zimbabwe, like the areas around the two major cities of Harare and Bulawayo, has a large concentration of poor people crowded into Communal Areas, and few remaining woodlands. India is the most densely populated of all four of these nations. The Deccan Plateau of India has many indigenous wild cucurbits, a high population density and widespread deforestation.

Our objectives were to: (1) Arrange for acceptability testing of rootfuel by local women, (2) Find new indigenous rootfuel species using local botanical talent, (3) Plant seeds locally using local gardening/farming talent, and (4) Build local capacity to deal with the problem indigenously. Our intent was to encourage local people to recognize that they know a lot about their own botanical resources, that there are many species that grow large roots rapidly and that some will be better than woodfuel. It was our intent to seek out and work with indigenous research institutes and non-governmental organizations that support grassroots efforts to improve quality of life. We report herein on the work in progress.

Rootfuel Studies in Mexico

Tests of acceptability of *C. foetidissima* rootfuel were carried out in four rural locations in central and northern Mexico, three desert sites and one semi-arid mountain site. We observed, along with our Mexican collaborators, Angel Roldan and Juana Diaz from the indigenous non-governmental organization, Maderas del Pueblo, and Victor Blanco from a related organization, ANADEGES. In one of the sites in Coahuila State on the Chihuahuan desert (Ejido Guelatao), *C. foetidissima* had been planted and successfully grown earlier by a skilled local farmer, and the roots harvested, cut into appropriate sizes and dried just before our visit. At another site nearby, Sacramento de la Jaroza, Coahuila, we used dried roots from wild colonies that the community had collected and dried, since their *C. foetidissima* seed had not germinated due to drought. In Coecillo, Guanajuato, the roots of the cultivated *C. foetidissima* plants were still small, so the family gathered wild roots for the test. In San Jose de la Cruz, Zacatecas, roots of a newly-found species had not dried completely so the cook used some *C. foetidissima* rootfuel that we brought.

In all four cases, the cooks remarked that the rootfuel was easy to ignite, that very little smoke was produced (less than from fuels normally used), that the odor from burning was not irritating, that the meals were normal in flavor, and that the coals were firm and therefore valuable for secondary uses. The experiences at Ejido Guelatao, Coahuila, and Coecillo, Guanajuato, were the first, anywhere, in which local people took the initiative to carry out all rootfuel activities, from planting the seed to cooking the meal.

In August 1993 we found two new species with large roots, later identified by our botanist, Fernando Gomez Lorence of the Instituto de Investigación de Zonas Deserticas, who accompanied us: (1) *Cucurbita radican* Naud ("sanacoche") found in the State of Mexico near Dolores Hidalgo; and (2) *Cucuribitopsis buraeavii* ("acolaista" or "acualiaiste" or "calabaza silvestre") found in Monte Escobedo, Zacatecas. Both seem to be native to regions that are transitional between semi-arid and semi-humid mountainous ecosystems. These results suggest that although *C. foetidissima* is likely to be the favored rootfuel species in Mexico, there are other species that show promise especially for the less-arid deforested regions. These species have been planted in test seed plots in these sites and roots have been gathered for cultural acceptability testing in Monte Escobedo. Further, *Cucurbita foetidissima* has been planted in several sites in Coahuila and Guanajuato.

In the State of Mexico, seeds of *Cucurbita radican* were planted by a local farmer but the young plants were pulled up by other farmers who consider this plant to be a weed. In Monte Escobedo, Zacatecas, the *Cucurbitopsis buraeavii* plot was destroyed by drought since it was not near a source of irrigation water. More plots of each of these are planned, with better provisions for care, as well as new plantings of *Cucurbita foetidissima*.

Rootfuel Studies in Brazil

With a country so large and geographically diverse as Brazil, the initial task was to choose a highly populated region with a woodfuel shortage and a semiarid climate, where people cook over open fires. The *caatinga* of northeast Brazil was selected. Joao Helder of Visao Mundial, a non-governmental organization with good infrastructure in community development, offered to coordinate. Dr. Lucia Ribveiro de Oliveira, education extension, and Dr. Itajai Helio Silva, botanist, both of the University of Bahia agreed to cooperate, the former in a survey of household fuel use and health, and the latter in new species identification. Profa. Vera Lucia Gomes-Klein, University of Goias, botanist and expert on wild cucurbits of Brazil, agreed to consult on new species. She had studied several Cucurbitaceae for her thesis, including *Wilbrandia glaziovii*, *Wilbrandia ebracteata*, and *Apodanthera glaziovii*, all of which produce large taproots. The Center for Research on Semiarid Tropics offered several people to assist in the agronomy of rootfuel.

Successful acceptability tests using *Cucurbita foetidissima* rootfuel that we took to Brazil were carried out in two sites, Fazenda dos Anjicosin, Pernambuco State, and an urban house near the University of Bahia. Both families use wood almost exclusively and cook indoors. The tests were conducted by the women themselves, and neighbor women came to observe. The consensus was that rootfuel would be an interesting alternative to cutting and carrying thorny mesquite-like wood, or other hardwoods, which are in short supply.

Seeds from *Cucurbita foetidissima* taken to Brazil in November, 1994 were planted in two test plots in the Juazeiro/Petrolina region-- one in a village and one at an agricultural research station--and in the herbarium in the University of Goias, Goiania by Dr. Gomes-Klein, who reported success. The University of Bahia planted *Cucurbita foetidissima* in early 1994 but the results were not positive. In January 1995, another trial was planted after treating the seed to increase germination, but even so germination was low. Then the region was afflicted by a severe drought and the University cut off irrigation to all of its experimental sites. Plans are now being made for a new trial with fresh seed that Dr. Bragg has taken to Brazil. This time three sites will be planted to increase success rates, in two experimental stations and on a farm where water is available.

Plans are for Profa. Gomes-Klein to join Dr. Bragg in May 1995 for seed collection of the species *Wilbrandia ebracteata*. The seeds will be planted in two test sites in an experimental station in Pernambuco as well as in the herbarium of the University of Goias.

Interviews of 210 families in the Juazeiro municipality (county) contain significant information on socio-economic aspects of woodfuel for cooking, perceived health effects, disposition to plant rootfuel for cooking fuel, etc. This survey was carried out in late 1994 by the team of Profa. Lucia de Oliveira, head of educational research, Profa. Maria Goretti A. de Souza, and four student interns.

Rootfuel Studies in Zimbabwe

Our botanist in Zimbabwe, Mary Wilkins/Ellert, identified two local species on the basis of her previous experience and a study of the botanical literature: *Cucumis hirsutus* Sond. and *Acanthosicyos naudinianus* (Sond.) C. Jeffrey. Both produce taproots. *Cucumis hirsutus* roots were collected in the Bulawayo area where it is common, and where there are large, well-populated Communal Areas suffering woodfuel shortages due to deforestation. Communal Areas are lands of lesser quality reserved for black Zimbabweans who depend on woodfuel, dungcakes and crop residues to cook meals. *Cucumis hirsutus* grows in many soil types, but *Acanthosicyos naudiniana* is restricted to Kalahari and Karroo sands. This required a trip to the Hwange area for root collection. Rootfuel was prepared from both species by sun-drying the roots.

With the cooperation of field workers of the Lutheran World Service, it was arranged for acceptability tests to be carried out by women of the Zvishavane Communal Area in the Midlands of Zimbabwe. *Sadza*, a staple food of the Shona and Ndebele peoples of Zimbabwe, was cooked over each of the two new rootfuels and also *mopane*, a typical woodfuel of the region. We provided the maize meal and the fuels, gave no special instructions to the cooks, and documented what the cooks did and said. Present in the hut were one of us (EBS), botanist Wilkins/Ellert, development researcher Peter Mudungwe of the Lutheran World Service, others of his staff, and a group of village women who had been elected as observers. Other women waited outside for news.

The hut was a typical poorly-ventilated African round dwelling with conical thatched roof, one small window and one door. The cooking of the *sadza* in a simple open fireplace in the middle of the floor was recorded by video. *Sadza* is a thick corn-meal mush prepared by pouring meal into boiling water, stirring vigorously while continuing to heat the pot, and later adding more meal to stiffen the mush. A summary of the results follows:

Mopane (woodfuel). Difficult to ignite. Fifteen minutes were required for the water to come to a boil. Seven minutes were required to complete the *sadza* after first addition of meal to the boiling water. Smoke accumulated, then began to sting the eyes after about 15 minutes, and was bothersome during the remainder of the time. According to later discussion with the cooks and observers, this was typical.

Cucumis hirsutus (rootfuel). Readily ignitable. Nine minutes were needed for the water to come to a boil. Eight minutes were required to complete the *sadza* after first addition of meal to the boiling water. No smoke was evident in the room. This is apparent from the video footage, which can be made available to readers of this paper. The village women were especially interested in this fuel.

Acanthosicyos naudiniana (rootfuel). More easily ignited than the woodfuel, but not as easily as *C. hirsutus* rootfuel. Eleven minutes were required for the water to come to a boil, because the cook added too much fuel too quickly and the fire was nearly smothered. The *sadza* was completed six minutes after first addition of meal to the boiling water. Smoke was produced during the smothering episode, but it cleared up after that. This smoke was considered to be less irritating than the smoke from the typical woodfuel, *mopane*.

The women commented to one another in the Shona language, and the translator recorded the comments in English. About the *Cucumis hirsutus* rootfuel, the women said "this fuel is easier to start," "the smoke does not sting the eyes as much as normal firewood," "there is less smoke," "the smoke is odorless," "the smoke is sweet," "we are using less fuel than if wood were being burned." About the *Acanthosicyos naudiniana* rootfuel, the women said "the smoke smells sweet," "this one smokes more than the other one (*Cucumis hirsutus*)," "we are using less fuel than if we were burning wood."

After the maize meal was added to the boiling water the *sadza* was finished in about the same time, in all three tests. But with the two rootfuels, the boiling point was reached sooner than when wood was burned because of better ignitability. Both rootfuels were judged by the women to be superior to *mopane* woodfuel.

The women examined the coals for their value in secondary uses, and it was judged that coals from the *Cucumis hirsutus* would be suitable for use in the iron (to iron clothes), but that coals from the *Acanthosicyos naudiniana* were not firm enough for this purpose.

Nearly-smokeless fuel, more desirable than wood, can be obtained from roots of the native wild cucurbit, *Cucumis hirsutus*, found in a wide range of environments in Zimbabwe and much of the rest of southern Africa. Although rootfuel from *Acanthosicyos naudiniana* had advantages over woodfuel, this plant grows only in sands not widely found in Zimbabwe, and its rootfuel was less satisfactory than that of *C. hirsutus*.

At the onset of the rainy season, in November 1993, Ms. Wilkins/Ellert planted a small seed nursery. *Acanthosicyos naudinianus* was not included because it apparently has an unidentified germination inhibitor. Only seeds of *Cucumis hirsutus* from Bulawayo, and *Cucurbita foetidissima* from the U.S. were planted, the former in local garden soil and the latter in garden soil with amendments to improve drainage. *Cucumis hirsutus* roots after three months were thin, typically with potato-like swellings, and the roots did not dry satisfactorily even though the plants had grown well. The roots did not resemble the older, wild *Cucumis hirsutus* roots that had been tested successfully at Zvishavane. By contrast, the *Cucurbita foetidissima* plants did not flower, but the roots were satisfactory in shape and size, and they dried properly. Therefore, *Cucurbita foetidissima* may hold more promise. However, the introduction of an exotic species such as this one must be approached with caution, and further studies carried out.

Both of these test plots are located at Bulawayo, 20 degrees south latitude, in Zimbabwe's Natural Region IV (semiarid, 14-26 inches of rainfall). At almost the same north latitude in

Mexico (22 degrees), one finds San Luis Potosí where there is a climate very similar to that of Bulawayo and wild *C. foetidissima* prospers. Further, no unusual insect damage on this species was noted in Bulawayo. Therefore, we are encouraged that *Cucurbita foetidissima* may develop into an effective rootfuel species in Zimbabwe.

By comparison, *Cucumis hirsutus*, a wild cucurbit of southern Africa, grew very slowly. Further, the swellings on some but not all roots may be explained by a plant disease that hinders growth. On the other hand, the slow growth may be normal for this species. Growth rates of wild cucurbits depend on many variables, including numbers of leaves per root, and leaf area, and *Cucurbita foetidissima* excels in both.

Rootfuel Studies in India

We selected three locations on the Deccan Plateau for rootfuel studies: **(a)** the Centre of Science for Villages (CSV) in central India, **(b)** the Nimbkar Agricultural Research Institute (NARI) on the west side of the Deccan Plateau not far from Bombay, and **(c)** the Gandhigram Rural Institute (GRI) in south India, not far from Madurai. The work at these locations is still in progress as of this writing in May, 1995.

The CSV is a research institute for the needs of rural people at about 21 degrees north latitude in central India at Wardha, Maharashtra State, near Nagpur. It was agreed that CSV would plant *Cucurbita foetidissima* test plots, search for promising species of indigenous cucurbits, and arrange for rootfuel acceptability tests by local women. The seed nursery will be directed by Dr. Devendra Kumar who heads CSV, the search for new species will be carried out by Dr. Tarak Kate, botanist, and the acceptability studies by Dr. Vibha Gupta who is expert on rural women and cookstoves.

NARI is at about 18 degrees north latitude in Phaltan, Maharashtra State, on the western side of the Deccan Plateau, south of Pune. NARI will plant *Cucurbita foetidissima* test plots under the direction of Dr. Nandini Nimbkar, agronomist. A successful acceptability test of *Cucurbita foetidissima* rootfuel was carried out by a local woman while we visited Phaltan. NARI has reported on the results of its first test plot of *C. foetidissima*. A high germination rate (64%) was attained in polyethylene bags in the nursery. The plants were then transferred to a location some kilometers from NARI's main campus where a typical immature (rocky) soil of the region was available, with irrigation capacity. The planting failed because of severe conditions (high air temperature, low humidity) and the permeable nature of the rocky soil. This test was our first in rocky soil. The result indicates that a more mature soil is needed for this plant, or that rocky soils must be heavily amended. The next trial will be in a more mature soil.

GRI, a university dedicated to the needs of rural people, is located in Dindigul, north of Madurai in Tamil Nadu State in the south of India at about 10 degrees north latitude. We conducted a successful acceptability test of *C. foetidissima* with Dr. T. Karunakaran of GRI and his staff. It was agreed that GRI will choose a botanist to search for promising indigenous cucurbits in the south of India, and plant test plots of *C. foetidissima*.

Analysis of Technical Aspects and Policy Implications

Testing Acceptability, Finding Indigenous Species, Planting Test Plots

In all tests, the cooks found rootfuel to be acceptable. Typically, complimentary remarks were volunteered about the ease of ignition, the small amount of smoke, the non-irritating burning odor (even "odorless" or "sweet"), and that the food was normal in flavor. Some cooks noticed that they were using less fuel, in comparison with wood.

Globally, there may be dozens or even hundreds of species with rootfuel potential (large-rooted, fast-growing in a variety of soils). Only a few have been tested. In this project, two new promising species were identified in central Mexico, three in Brazil, and two in Zimbabwe (but one of the latter was eliminated). We expect a number of promising species to be found on the Deccan Plateau of India because the well-known Indian expert on cucurbits, H.L. Chakravarty (1959) has published on so many.

The test plot results were mixed. Two plantings were carried out successfully in Mexico by local initiative from start to finish. In northeast Brazil, all plantings failed due to a severe drought. In the case of one plot on an agricultural experiment station, the municipality cut off all water to all crops on the station. In Zimbabwe, *C. foetidissima* roots were successfully grown, but flowering did not occur. And *Cucumis hirsutus* plants flowered, but the roots showed signs of disease. One plot in India failed. It had been planted in rocky soil and emerged under severe drought conditions. Another plot in better soil in a different part of India (Wardha) is one-month old, and looks fine so far.

Much has been learned from this test plot experience. Even if irrigation capability exists, under unusually droughty conditions all water can be cut off summarily by water authorities. A multiplicity of plots in different municipalities would hedge against this. Daily inspection is advisable, and previous experience in gardening in a specific location is valuable. This may permit a peasant gardener to accomplish even more than a degreed agronomist. So planting test plots at agricultural experiment stations is not mandatory. We conclude that despite setbacks at some test plot locations, *C. foetidissima* is likely to be grown successfully in most if not all of these places, eventually, unless subjected to unusually severe growing conditions. We cannot draw conclusions on other species as yet.

The Near-Smokelessness of Rootfuel: Why?

Of major importance was the combustion of rootfuel in a nearly smokeless manner, noted immediately by cooks and recorded by video (copy available on request). The relative smokelessness of rootfuel appears to be related to its nature as a carbohydrate. It is starchy and cellulosic, not woody, and remarkably low in lignin compared to wood. Apparently, it is easy to pyrolyze wood but difficult to supply it with air quickly enough so that the rapidly-evolving volatile products of pyrolysis can all be burned. The unburned pyrolysis products are then given off as smoke. By contrast, rootfuel burns at about one-third the rate of comparable sizes and shapes of woodfuel (Duke 1988; also see Shultz et al. 1990). This apparently relates to a slower rate of evolution of volatiles when starch and cellulose pyrolyze, in comparison with a higher rate of evolution from lignin. The lignin content of rootfuel is very low, confined mainly to the cortex (skin) of the root.

Also notable is that cucurbit roots can be quickly dried in the sun to a very low level of moisture content, almost bone dry, certainly much drier than typical woodfuel. Even wood that is seasoned for a year will contain 20 percent moisture, and this promotes smoldering and smoke production. By contrast, rootfuel can be dried almost completely in a few days or weeks, depending on root size, air temperature, and air humidity.

Does rootfuel *always* burn smokelessly? No. We and our cooks have demonstrated that if rootfuel is not well-dried or if we smother the fire with rootfuel, smoke will appear. Clearly, near-smokelessness requires dry rootfuel and an adequate air supply to the fire.

Two Major Policy Issues

1. Woodfuel plantationing is not a desirable intervention for coping with the woodfuel problem. The continued support for woodfuel plantationing by lending and aid agencies should be reconsidered in the light of the well-known health hazards of woodsmoke publicized so well by the World Health Organization. Our conversations with officials suggests that the health hazards of smoke from wood, dung and crop residues are widely understood, but that officials don't know what else to do but promote woodfuel plantationing. Many realize that woodfuel has failed, but at the same time they do not regard rootfuel as "proven." So funding continues for woodfuel plantationing, an intervention that, quite arguably, has been *proven to be a failure*.

2. As an intervention to alleviate indoor air pollution, rootfuel may have greater viability than improved stoves, bottled gas or solar cookers. Rootfuel appears to be inexpensive and easy to grow, harvest and dry, and it does not require the construction or purchase of a special stove. It works well in the three-stone fireplace, the principal stove of the poor. By contrast, the weaknesses of currently favored interventions are clear. Bottled gas and improved stoves cannot be afforded by the poor majority. Improved stoves rely heavily on chimneys and these simply transfer the smoke outdoors, so it comes back in through windows and doors. Solar cookers may be too expensive for the poor, or culturally unacceptable. Further, these interventions will require major and expensive efforts for deployment and dissemination, far from the auto-diffusibility ideal. By contrast, the relative simplicity of rootfuel technology may place it closer to auto-diffusible, and therefore, a lower-cost intervention.

Rootfuel is very likely to be simple to grow and utilize, an intervention that is relatively simple to explain in concept and quick to put into action if seeds can be made widely available at low cost. Every aspect of rootfuel is within the competence of rural women to implement with a minimum of initial extension support. For example, rootfuel is used in a manner very similar to woodfuel, and it can be grown in much the same way that familiar crops are grown, such as squash, a member of the same plant family.

Conclusions

Near-smokelessness strengthens rootfuel as an intervention to alleviate indoor air pollution and adverse health impacts on women and children. Currently favored interventions are unaffordable by the poor. Rootfuel appears to be appropriate for the large majority of the population, including the poor. Its existence calls into question current policies that support woodfuel plantationing, thereby perpetuating woodsmoke-related illnesses. Rootfuel's carbohydrate character, low in lignin content and quickly dried to a very low level of moisture, appears to be responsible for its attractive combustion properties.

It is possible that there are hundreds of species of plants that may have rootfuel potential, world-wide. Only a few have been tested thus far. A successful search for clean-burning non-woody biofuels will be no small achievement of limited practical utility and narrow academic significance. It could bring substantial health, economic and environmental benefits to as much as half the world's population, some 2.5 billion people or more who are presently dependent on woodfuel, dungcakes and crop residues for cooking meals.

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CARBOHYDRATE BIOFUELS II: THE NEED AND THE POTENTIAL FOR ROOTFUEL IN THE NAVAJO NATION

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Abstract

Over 80% of rural Navajos and about two-thirds of all Navajos use scarce woodfuel and low-grade coal for home heating half the year, with coal used mainly as a nighttime adjunct. Serious health problems arise because stoves are old and leak smoke and carbon monoxide. The impacts are gender-biased to women and small children. Respiratory disease is a major cause of Navajo mortality and unusually high admissions to Navajo Indian Health Service hospitals. A 1990 study at a Navajo hospital showed that Navajo children under two years of age from homes with woodstoves are nearly five times more likely to contract acute lower respiratory tract infections than children from homes with no stove.

Correctives include improved stoves and fuels. Our previous studies on clean-burning starchy/cellulosic "rootfuels" in Latin America, Africa and Asia are applicable. We discuss our preliminary work on the Navajo reservation, the current status of household stoves and stovefuels, the health impacts of woodsmoke and coalsmoke from old, faulty stoves, the conditions for growing rootfuel on the reservation, and policy and strategy for coping with the problem. Our work was sponsored by the Western Regional Biomass Energy Program of the U.S. Department of Energy.

Introduction

Woodfuel and low-grade coal are the most important household fuels in the Navajo Nation. About two-thirds of all households, and over 80 percent of rural homes burn wood and the majority of those also burn coal. Because many stoves are old and faulty, woodsmoke and coalsmoke and probably carbon monoxide (CO) leak into homes during the six-month heating season. The main health problems caused by woodsmoke and coalsmoke are respiratory diseases, biased to older women and younger children. Problems from chronic exposure to low levels of CO may also prove to be important if more were known about adverse reproductive outcomes (AROs) and cardiac problems that might be due to CO from smoldering fuel, especially coal, in old faulty stoves.

Frequently discussed corrective actions fall into two broad categories:

(a) Repair or replacement of old leaky stoves and stovepipes to ensure that smoke is conducted outdoors. However, this would not prevent the remaining woodfuel on the reservation from being consumed, driving up costs as woodfuel must increasingly be imported from off-reservation.

(b) Adoption of clean-burning fuels, to avoid smoke. Examples are natural gas, and "bottled" LP-gas (propane and butane), but for most Navajos, natural gas is unavailable and LP-gas is too expensive. Only a small percentage of Navajos can afford these commercial fuels.

Therefore, we considered a novel solid biofuel ("carbohydrate rootfuel") that burns with very little smoke, and that can be grown on the reservation under irrigation. It is made by sun-drying the fast-growing starchy (non-woody) roots of a southwestern wild melon plant, *Cucurbita foetidissima*. In the summer of 1994, it was grown successfully under irrigation at New Mexico State University's agricultural experiment station in the northeastern part of the reservation (Smeal and Gregory 1994). Rootfuel is still being researched, so it is not yet available to Navajos.

We report here on some of the results of a 1994 project sponsored by the Western Regional Biomass Energy Program of the US Department of Energy. We have reviewed progress of this project at earlier stages in two previous papers (Shultz et al. 1994; Shultz et al. 1995).

Household Stoves and Stovefuel on the Navajo Reservation

The Prevalence of Old Leaky Stoves

According to the 1990 Census, 57.4% of Navajo families were living below the poverty level, about one-third were on public/general assistance, and unemployment was at 27.9%. About half the homes lacked electricity and indoor plumbing, and over three-quarters had no telephone. Clearly, most Navajos cannot afford LP-gas or good woodstoves and so during the six-month heating season (October to April) they are chronically exposed to woodsmoke and coalsmoke, and probably low concentrations of carbon monoxide.

Many stoves are fashioned from old steel drums that allow smoke to escape into the room. Other stoves are home-welded from ill-fitting steel plates. Old manufactured cast-iron stoves often are cracked, and stovepipes often do not fit properly. Smoke smudges on walls and ceilings give visual evidence of leakage.

Demographics

There are at least 155,000 Navajos residing on the reservation, and the majority (68%) are rural people. Small towns of 200 to 2000 persons are home to 11% of the Navajos, and 21% live in a few larger towns: Shiprock, NM (7687 persons), Tuba City, AZ (7323 persons), Chinle, AZ (5059 persons), Kayenta, AZ (4372 persons), and the Ft. Defiance, Window Rock, St. Michaels complex of three neighboring towns in Arizona that includes a total of 8914 persons (Census 1990). The larger towns are fairly well distributed: Shiprock is in the northeast of the reservation, Kayenta in the north, Tuba City in the west, Chinle in the central part, and the three-town complex is in the south-central region.

Wood as a Household Fuel on the Navajo Reservation

The 1990 census probably underestimated the use of wood as household fuel. From data in the *Navajo Nation Profile* (1993) it can be calculated that 54 percent of occupied housing units (OHUs) burn wood. However, the Navajo are 68% rural, and rural use of wood has recently been calculated by Larry Rodgers (1995) to be about 83 percent. In addition, Rodgers (1994) has stated that use of wood and wood/coal is significant in the towns where woodstoves are typically installed in housing projects. He reports (1995) that 26.4% of occupied housing units in the 29 towns use woodfuel, and 3.1% use coal.

Based on this, we calculate that about 66% of the total Navajo population on the reservation uses wood or wood supplemented with coal for home heating (Shultz et al. 1995). Since the 1990 Census counted 37,000 occupied housing units (OHUs), it follows that about 24,000 OHUs have wood or wood/coal stoves. Most homes have one stove. The estimate of 24,000 stoves must be treated as a minimum, because the Navajos have persuasive reasons to believe that they were undercounted in the 1990 Census (Rodgers 1994).

Scott Russell (1980), in a 1970s field study of woodfuel usage in a small sample of Navajo households, estimated that about 11 pickup truckloads were required for one family, annually, for space heating and cooking. Values ranged from 7 to 15 loads. The trucks were rated half-ton. Since then, the population of Navajos on the reservation has risen, poverty is still prevalent and Navajos still cannot afford LP-gas, so pressure on the woodlands continues to increase. If the value of 11 pickup truckloads is valid, we estimate that the total woodfuel use is currently about 130,000 tons per year. Much of this now comes from off the reservation, for example, from the Cortez, CO area.

Trees on the reservation are protected, but the ranger staff is very small. Only trees that are "dead and down" (D&D) can be legally taken for firewood, and only from the designated woodlands. No-cost permits for firewood gathering are required. Although traditional Navajo culture bans the cutting of living trees, we believe that economic necessity is driving many Navajo families to this extreme. There seems to be little or no "dry" (D&D) wood left on the reservation. According to Russell (1980), common ownership of woodfuel resources had ceased in parts of the reservation in the 1970s, and many Navajos had begun to protect the trees on their own grazing area, as a scarce resource. We think the situation has worsened significantly since then.

Woodfuel is not really a "free good," even if it is collected in the woodlands of the reservation. There are opportunity costs, and costs associated with using the pickup truck, which may have to be driven for substantial distances to find woodfuel, even off the reservation. Also, chainsaw accidents do occur.

Coal as a Household Fuel on the Navajo Reservation

Low-grade coal (sub-bituminous B and C) is widely used by Navajos as an adjunct fuel, supplementing wood as the principal stove fuel. Wood et al. (1979) reported that 90 of 146 randomly sampled Navajo households (61.6%) burned coal as well as wood. However, from data given in the *Navajo Nation Profile* (1993) it can be calculated that only 6.6 percent of occupied housing units (OHUs) burn coal, a remarkably low value. The census was taken during April, May and June, largely *after* the heating season, when people were not likely to burn coal. Coal usage is mainly a winter night phenomenon, typically added to a wood fire at bedtime to bank the fire for the night.

Also, the way the census fuel-usage question was asked may have masked a significantly higher adoption of coal as a household fuel than just 6.6 percent of the total occupied homes. We suggest that householders may have interpreted the census question to mean which fuel is the *main* fuel, and so they indicated wood, even though they may actually use a lot of coal along with wood during winter nights. Further, some people suggested that the growing shortage of available D&D wood and the ready access to coal (either free or inexpensive) have stimulated consumption of coal in recent years. Others tell us that coal usage is not increasing.

Russell (1980) estimated that coal-using families collected, annually, an average of 2 pickup truckloads of free coal, in addition to an average of 11.4 loads of woodfuel. He estimated that one load of coal was equivalent to two loads of woodfuel in terms of heat content, and confirmed that coal is mainly used to bank the fire overnight.

Some Navajos remark that they resist using coal because it "smells," or it "soots up the chimney" or simply because woodfire is a traditional part of the culture. But we believe that others are turning to coal due to its ready availability and low cost. If Navajos appear at a mine at posted times with a pickup truck, they can fill the truck free of charge at some mines and for a small charge at others. Coal is also sold by Navajos in local flea markets.

Woodfuel and Rootfuel Compared

All wood contains lignin, the biochemical component of wood from which most of the smoke originates. Apparently, it is easy to pyrolyze wood but difficult to supply it with air fast enough so that the rapidly-evolving volatile products of pyrolysis from the lignin can all be burned, much of which is therefore evolved as smoke.

Starchy/cellulosic rootfuel made by drying the taproots of a semiaridland plant (*Cucurbita foetidissima,* "buffalo gourd") burns at about one-third the rate of comparable sizes and shapes of hardwood woodfuel (Shultz et al. 1990). This slow rate and the minimal production of smoke apparently relate to a slower rate of evolution of volatiles when starch and cellulose pyrolyze, in comparison with a higher rate of evolution from lignin. The lignin content of rootfuel is low, confined mainly to the cortex (skin) of the root.

Even seasoned woods contain a lot of moisture after one year, about 20%, and this promotes smoldering and smoke production. By contrast, rootfuel can be dried to almost zero moisture content in a few weeks. In comparison with wood, the combustion advantages of carbohydrate rootfuel arise from two features: its much lower lignin content, and its ability to quickly lose virtually all of its moisture content.

Health Impacts of Woodsmoke, Coalsmoke, and Carbon Monoxide (CO), and The High Incidence of Respiratory Disease on the Navajo Reservation

The Adverse Health Impacts of Indoor Woodsmoke

There is substantial information in the published literature on this topic, much of it reviewed by the World Health Organization (1992). The message is unequivocal. Whether data are collected in the New World or the Old, people exposed to woodsmoke are more likely to suffer respiratory diseases than those who are not exposed. Elderly women and small children are especially vulnerable in any locality or culture. Recent research reports in *Science* magazine (Anon. 1995, 1771) show that woodsmoke constituents suppress the macrophages of the immune system so respiratory pathogens can't be readily defeated.

The Impacts of Smoke and Carbon Monoxide (CO) Distinguished

Although smoke and CO are produced together and can leak into the home together from faulty stoves or stovepipes, the health impacts are not the same, and they affect different groups of people. Smoke is especially hazardous to the health of infants and small children. Because older women probably have accumulated more time than men in the presence of indoor smoke, they also are an especially vulnerable group.

But the presence of even low concentrations of CO in the home can affect the development of the fetus (Coultas and Lambert 1991), and cause adverse reproductive outcomes (AROs). It has been established that CO is transferred across the placenta and into the fetal circulation (Longo 1970, 313). In animal studies, elevated CO concentrations have caused an increase in fetal death rate, and a decrease in postnatal weight gain in survivors (Astrup et al. 1972, 1220-2). Low levels of CO can also bring about cardiac events that are triggered by lack of oxygen in the blood. This is important to individuals with certain pre-existing cardiac conditions (Coultas and Lambert 1991).

The Hazards of Burning Wood and Low-Grade Coal Compared

We suspect that smoke from low-grade high-volatile sub-bituminous B and C coals of the Navajo reservation is more problematic than woodsmoke, as the World Health Organization (1992, 26) suggests ("...coal seems to represent a substantially worse health hazard than most biofuels"). Our concern stems in part from the high inorganic (minerals) content of these low-grade coals, as well as the way in which the coal is used at night which risks the generation of carbon monoxide because the coal smolders. Navajo coals are high in inorganic content, many in excess of 20%. This probably means large amounts of respirable particulates in the smoke. Also, certain coal inorganics such as mercury, uranium, arsenic and cadmium can be very dangerous to human health, if enough is present in the coal. These elements are not significant in wood ash.

Also, a large amount of very light ash is produced when these low-grade coals are burned. A significant portion of this ash is respirable, and tends to blow out into the room when the stove door is opened to insert more fuel. Also, quantities of respirable particulates can also escape into the room air when the stove is cold, during the ash removal process. In short, low-grade coal produces more ash and more potentially-hazardous ash than woodfuel.

The Tuba City Hospital Study

A significant study of health impacts of household wood/coal smoke, specific to Navajos, was carried out on Navajo children two years of age and younger at the Indian Health Service Hospital in Tuba City, AZ (Morris et al. 1990). Children exposed to woodsmoke were 4.85 times more likely to contract bronchiolitis and pneumonia than those who weren't. In our opinion, the high odds ratio of 4.85 would have been lower if the stoves had been good stoves. So the value of 4.85 is partly due to the inherent health hazards of woodsmoke and coalsmoke, and partly due to Navajo inability to afford good stoves.

Respiratory Illnesses, a Major Problem for Navajos

Respiratory diseases are the leading illnesses that cause hospitalization among Navajos, with 14.4% of IHS admissions in 1992 (IHS 1994). Only obstetrics is more important. Respiratory illness is the third leading cause of outpatient visits, accounting for 149,171 visits in 1994 (NAIHS 1994). It is the fourth leading cause of death amongst the Navajo, according to the most recent data available, data from 1989-91 (IHS 1994).

Pediatricians at the Navajo Area Indian Health Service (NAIHS) are aware of the contribution of woodsmoke to pneumonia in children. Mothers of babies with bronchiolitis and pneumonia are routinely advised to take the baby to stay with relatives who have central heating, according to Dr. Louise M. Abel (1994), a physician at the Northern Navajo Medical Center in Shiprock, NM.

Dr. Abel cares for many elderly patients with lung disease who deteriorate during the winter partly due to wood and coal use and the ensuing indoor air pollution. Each winter, asthma patients face increased numbers of attacks, visits to the emergency room, and more medications and hospitalizations. While "flu" season plays some role in this deterioration, Dr. Abel feels that chronic exposure to woodsmoke and coalsmoke is the main culprit. There is general agreement that the indoor woodsmoke problem is serious, and that the blame cannot be attributed to cigarette smoke in the home because few Navajos smoke. It is widely agreed that woodsmoke and coalsmoke are far more prevalent than cigarette smoke in the Navajo home (Shultz, Bragg, Watson, Topaha and Abel 1995).

The Unresolved Question of Low-Level Exposure of Navajos to CO During the Nights of the Heating Season

We are not sure that the use of coal in old leaky stoves under reduced-draft conditions produces CO concentrations high enough to cause adverse reproductive outcomes (AROs) such as low birthweight, and perhaps other disorders. But the possibility must be taken seriously. If a large percentage of the Navajo people, as much as two-thirds (the percentage who heat with wood and wood/coal) is indeed being exposed chronically to low-concentration CO during the night for half the year, the health effects could be important.

Conditions for Growing a Clean-Burning Biofuel on the Navajo Reservation: Climate and Water

The reservation is on the Colorado Plateau, therefore, much of the land suitable for growing rootfuel from *Cucurbita foetidissima* is about a mile high in elevation. This provides a good climate for cultivation of this species, as it prefers a relatively cool summer temperature (Nelson et al. 1983). The growing season extends from mid-May to mid-October. The wettest month is August with only 1 to 2 inches of rain (Goodman 1982). Although *Cucurbita foetidissima* requires less water than corn, irrigation is essential, and certainly the most water on the reservation is available from the San Juan River Project in the northeast of the reservation near the largest town on the reservation, Shiprock, NM.

According to Dr. Robert Becker, Hydrologist, Navajo Office of Water Resources Management, some surface water is also available at Leupp, Bird Spring, Many Farms, Navajo, Tsaile, Wheatfields and Ganado. For example, the Many Farms Chapter has a reservoir and a cooperative farm. Much water escapes from the reservation, and if more could be captured there would probably be sufficient for substantial enlargement of irrigated agriculture in many locations, not just near the San Juan River. The Little Colorado River may be further developed in the southwest corner of the reservation where the Leupp Chapter currently has a small farm cooperative. In addition to water impoundments, there are large aquifers that might be tapped for agriculture (Becker 1995).

Another potential farming site for rootfuel is Kerley Valley in the Tuba City Chapter, southwest of the town of Tuba City, along the Moencopi Wash. Amos Johnson (1995), Water Resources Engineer with the Navajo Office of Water Resources Management tells us that there is slightly saline water at about 30 feet deep at Kerley Valley. *Cucurbita foetidissima* tolerates some salinity, as found by one of us (Whittier) who carried out experiments on this at New Mexico State University, Las Cruces, some 10 years ago.

According to *Chapter Images* (1993, 41), a dam, canals and lift gates were built in the 1950s at Kerley Valley in a land rehabilitation program, but "due to under-use and blowing wind, the canals were filled with sand and tumble weeds." Part of the canal system was rehabilitated in 1985, and it is estimated that there are 15 family farms now (Johnson 1995). Kerley Valley is significant because Tuba City is almost as large as the largest Navajo town (Shiprock, NM), Tuba City is growing rapidly, and there are no woodlands around it. All fuel must be "imported" to this important population center of over 7000 persons, far from Shiprock's abundant supply of water from the San Juan River.

Taking Action: Analysis, Policy and Strategy

The need to deal with indoor smoke in Navajo households is health-driven by unnecessary suffering of many Navajos, especially older women and small children, and costly medical treatment for avoidable smoke-related illnesses caused by woodsmoke and coalsmoke. Further, the need for a replacement for woodfuel is driven by a worsening woodfuel shortage on the reservation.

Some correctives will be more useful than others. None will come without cost, and so it is very likely that public money will have to be spent. If correctives are to be subsidized by public funds, objections will surely be raised. But public funds are already being spent by U.S. taxpayers on treatment of *avoidable* smoke-related illnesses at Navajo IHS facilities. If tax money is to be spent on correctives to reduce unnecessary suffering among the Navajo, then a portion of this money will be recoverable through lowered costs of services at Navajo IHS hospitals.

To keep smoke out of homes, immediate steps are needed to repair the worst of the estimated 24,000 stoves. Alternatively, the worst could be replaced with new, subsidized stoves, but there is a risk that some of the new stoves would be pawned or sold. So repairing a stove may be more practical if repair is feasible. Irreparable stoves could be replaced with older repaired stoves that might not be as readily sold as new ones.

Continued use of the reservation's low-grade coals in old, faulty stoves has serious health consequences. Coal use should be phased out. But this will put even more pressure on the failing wood supplies of the reservation. Currently, household use of coal with all its attendant health risks is taking significant pressure off of the remaining woodlands of the Navajo Nation, probably at a high health cost to the people and a high monetary cost to the IHS. Until large supplies of rootfuel can become available in several years, extra woodfuel might be imported to the reservation from locations in the southwest where wood is in more abundant supply. However, the higher shipping costs will have to be subsidized, along with the cost of stove repairs.

If rootfuel, a relatively clean-burning solid biofuel, is to eventually replace the imported woodfuel, then a major effort must be mounted as quickly as possible to domesticate this wild semiaridland plant of the southwestern United States, and to establish the economics of production at several places on the reservation. At this time, ample water will be available only in the northeast, near Shiprock, from the San Juan River Project.

It is uneconomic to ship biomass fuel for long distances because its market price tends to be very sensitive to shipping costs. The Navajo reservation is large, the size of West Virginia. Therefore, biofuel shipping costs will probably create the need to develop irrigation water supplies on the reservation at the western end, to serve the Tuba City region, and in the central and south-central part of the reservation, near the major population centers found there (Kayenta, Chinle, and the Ft. Defiance, Window Rock, St. Michaels complex). New water impoundments and canals will be required, and old ones must be rehabilitated. Large aquifers may need to be tapped. If rootfuel is to replace woodfuel and coal for most Navajos, the main technical and investment challenge will be to develop the infrastructure for irrigation water, but this will also stimulate agriculture in general and create new jobs.

Conclusions

We have studied the problems associated with woodsmoke and coalsmoke from old, leaky household stoves on the Navajo reservation. Nearly two-thirds of Navajos on the reservation, those who burn wood and wood/coal for space heating and for cooking, are at some risk of respiratory and other illnesses. It is widely conceded that *avoidable* respiratory illness caused by burning wood and coal in old, leaky stoves is significant. Of all diseases, respiratory illnesses cause the most hospitalizations of Navajos, mainly in publically-funded facilities of the Indian Health Service.

Options for corrective action include (a) repair or replacement of faulty stoves and stovepipes to ensure that smoke is conducted outdoors, and (b) adoption of smokeless or virtually smokeless fuels, to deal with the cause of the problem. These options cannot be afforded by most of the Navajo people, so government subsidies will probably be needed to mitigate the problem. Our study gave emphasis to the production of a nearly smokeless fuel, called "rootfuel," made by drying the roots of the buffalo gourd plant, *Cucurbita foetidissima*. Economic analyses are still to be done, but the technical feasibility of growing this southwestern plant on the reservation under irrigation was demonstrated in 1994.

Acknowledgements

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CARBOHYDRATE BIOFUELS III: CONSUMPTIVE-USE AND ROOT YIELD OF BUFFALO GOURD *(Cucurbita foetidissima* HBK)

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Abstract

Biofuel provided by the dried roots of the wild buffalo gourd, *Cucurbita foetidissima,* represents a potential, cleaner-burning alternative to other bio-fuels (ie. wood and coal) currently used for cooking and heating on the Navajo Indian Reservation. However, no information is available regarding the plant's water requirements for growth and viable root production on the Colorado Plateau in northwestern New Mexico where the Navajo Indian Irrigation Project is located. The primary purpose of this study was to evaluate the relationship between buffalo gourd root production and evapotranspiration under variable irrigation as provided by a line-source design. Total dry root yields ranged from 1.6 Mg ha^{-1} (0.7 tons/acre) to 11.4 Mg ha^{-1} (5.1 tons/acre), and increased linearly within an irrigation treatment range of 371 to 927 mm (14.6 to 36.5 in.), respectively. Peak average daily water-use of buffalo gourd providing maximum root yield was 8.6 mm (0.34 in.) and occurred in late July to early August. Results of this study indicate that buffalo gourd can be successfully grown in northwestern New Mexico when irrigated. Other observations during this study suggest that planting rates for optimum root production need to be established.

Introduction

Buffalo gourd (*Cucurbita foetidissima* HBK) is a wild perennial related to the cultivated squashes. It is native to arid and semi-arid regions of southwestern United States and northern Mexico (1). The plant develops wide-spreading, viny growth with age and produces many 5 to 7-cm diameter fruit. The large, fleshy tap root may reach weights of 50 kg (110 lb) in 3 to 4 seasons (1). The potential value of buffalo gourd as a crop plant, based on the high oil and protein content of the seed, was recognized by Curtis in 1946 (2). Subsequently, it was discovered that the root could be a potential source of food starch (3) or substrate for fermentation to fuel alcohol (5). Recently, it has been suggested that the sun-dried roots of the plant may represent a clean-burning, carbohydrate biofuel that could be used as an alternative to wood and coal for cooking and space heating in under-developed regions such as the Navajo Indian Reservation in northwestern New Mexico and northeastern Arizona (9,10). Although considered to be drought-tolerant, buffalo gourd grows most prolifically along roadsides or washes where precipitation runoff accumulates. It is absent or scarce on the Navajo Indian Irrigation Project (NIIP) in northwestern New Mexico where average annual precipitation is less than 200 mm. However, based on the reported range and desired habitat of the species, it is speculated that buffalo gourd would thrive on the reservation if provided with adequate soil moisture which could be supplied by the NIIP or other sources of irrigation.

Although no information related to buffalo gourd growth or water requirements on the high Colorado Plateau is available, a study designed to evaluate tap root production under different irrigation management strategies was conducted in southern Arizona during 1985 and 1986 by Nelson et al. (8). Generally, tap root yield increased with increased depths of irrigation within the range of 412 to 907 mm and a maximum tap root dry matter yield of 7.2 Mg ha^{-1} was observed at the greatest seasonal irrigation depth. In this study, and others conducted in Arizona (6,7), it was suggested that the low elevations and high summer temperatures typical of the study sites may be limiting factors in the growth potential of buffalo gourd.

The primary objective of this study was to evaluate single-season buffalo gourd root yield and consumptive-use relations under varying levels of uniform seasonal water stress at a higher elevation on the Colorado Plateau.

Methods and Materials

This study was conducted in northwestern New Mexico, U.S.A. at the New Mexico State University Agricultural Science Center at Farmington during 1994. The soil type at the site was a Wall sandy loam (Typic Camborthid of the coarse, loamy, mixed, calcareous, mesic family). Climate at the study site is semi-arid. The average annual precipitation is 193 mm (7.6 in) and the average annual temperature is 11°C (52°F). The average length of the frost-free period is 156 days from May 7 to October 11. The elevation above mean sea level is 1700 m (5600 ft).

Buffalo gourd seeds were planted at a depth of 12 mm (0.5 in.) on shaped beds (3 rows/bed) at a rate of 48 kg ha^{-1} (43 lb/acre) on May 16, 1994 using John Deere Flex-planters. Beds were spaced 864 mm (34 in) apart, center to center, and were situated parallel to three sprinkler-lines within a sprinkler line-source (SLS) plot design (4). The design (Fig. 1, top), although providing uniform irrigation to the crop when all three lines were operated simultaneously (ie. during germination, plant establishment and fertigations), provided continuous, decreasing gradients of water application on each side of the center sprinkler line when it was operated alone (Fig. 1, bottom) so that each planted bed received a slightly different level of irrigation. Catchment cans were used to measure irrigation water applied to alternate beds across the gradients throughout the growing season. Soil water was measured about every 10 days in 13 to 25 mm (0.5 to 1.0 ft) increments of the profile to a depth of 165 mm (6.5 ft) at alternate catchment can localities with a neutron probe. A standard U.S. Weather Bureau rain gauge located near the study plot was used to measure precipitation. Evapotranspiration (ET) at each irrigation level for each 10-day period was calculated using the water balance method:

$$ET = I + P - D + CSM$$

where:

ET = evapotranspiration, mm
I = irrigation, mm
P = precipitation, mm
D = drainage, mm
CSM = change in soil water, mm

Drainage of soil water below the deepest neutron probe measurement was negligible. Prior to planting, the plot was fertilized with ammonium nitrate (34-0-0) and treble super- phosphate (0-45-0) at rates of 84 kg N ha^{-1} (75 lb N/acre) and 86 kg P_2O_5 ha^{-1} (77 lb P_2O_5/acre), respectively. This fertilizer was disked into the soil at a depth of about 100 mm (4 in) . On four other dates during the season (July 1, July 20, July 29, and August 18), liquid N (32-0-0) was applied to the crop uniformly via nitrogation at rates of 19, 19, 20, and 15 kg N ha^{-1} (17, 17, 18, 13 lb N/acre), respectively. Additionally, a micronutrient solution was applied on July 1 at a rate of 8 kg ha^{-1} (7 lb/acre) and July 20 at a rate of 2.2 kg ha^{-1} (2 lb/acre). This solution consisted of 3.5% sulphur, 1% copper, 1% iron, 1% manganese and 4.5% zinc. To assist in weed control, the herbicide 'Prefar' was applied to the plot area on May 20 through chemigation at a rate of 6.7 kg active ingredient (a.i.) ha^{-1} (6 lb. a.i./acre). The plot was hand weeded three times during June.

Roots were dug by hand using soil forks and shovels from 2.1 m^2 (22.6 ft^2) replications at each end of the beds containing catchment cans on October 21, 1994. Subsequently, on November 3, roots were harvested with a tractor-drawn potato digger from all planted beds on one side of the SLS. Roots on the opposite side remained in the ground for evaluation of winter survival and root growth in the 1995 season. The average total root weight from three, 10-ft. long replications from each bed were used for yield determination. Roots from both harvests were weighed after being washed of excessive soil and air-dried. Root moisture content was determined by evaluating the difference between sub-sample fresh weights and oven-dry weights (105^{o} C for 48 hours) at each irrigation level.

Results and Discussion

Plant emergence (>50%) occurred on May 31 and actual established plant density averaged 607,620 ha^{-1} (246,000/acre) based on plant counts of June 9, 1994. This value represented 61% of the total seed planted and was about twice that expected based on a seed germination test prior to planting. Plant stand was highly variable over the plot ranging from 346,000 to 870,000 plants ha^{-1} (140,000 to 352,000 plants/acre) between random areas on each bed where counts were made. Forty-seven irrigations were applied to the plot between planting and vine desiccation (October, 7) at a frequency of 2-3 irrigations/week. Total irrigation water applied ranged from 267 mm (10.5 in) at plots farthest from the line-source, 14.3 m (46.8 ft) away, to 960 mm (37.8 in) at plots nearest the SLS or 2.2 m (7.1 ft) away (Figure 1B). An additional 104 mm (4.1 in) of precipitation occurred during this time period.

Total hand-harvested, dry, tap root yields within the SLS plot ranged from 2.4 to 12.2 Mg ha^{-1} (Table 1) and generally increased linearly with increasing irrigation depth ranging from 355 to 1064 mm (Fig. 2). The greatest average root yield (12.2 Mg ha^{-1}) however, was observed at a water application depth of 766 mm (709 mm ET), a depth 28% less than the irrigation maximum. The linear regression analysis indicated a dry root yield increase of 11.5 kg ha^{-1} with each mm increase in water application (Fig. 2). Analysis of the machine-harvest data provided similar results except that root yields were generally lower than hand-harvest at the low levels of irrigation (Fig. 2). It's possible that the smaller roots from the low irrigation plots fell through the chain of the potato harvester and became re-buried in the soil during the 11/3 harvest. Measured evapotranspiration was highly correlated with irrigation and averaged about 92% of water applied.

Average daily crop water-use during the season at the plot exhibiting maximum root yield (12.2 Mg ha^{-1}) is shown in Fig. 3. During the peak water-use period (late June through July), when temperatures were high and vines were large, the buffalo gourd crop utilized about 9 mm (0.35 in) of water per day.

Because of the variability in plant stand and the observation that root size was larger in border rows where plant competition was reduced, multiple regression analyses were used to evaluate the relationships between average weight per root, root weight per plot, root population and irrigation. Regressing root population and irrigation on weight per root yielded the

Table 1. Water Applied, Measured Evapotranspiration, Root Yield and Root Density of Buffalo Gourd at Each Irrigation Level of the Line-source Plot Based on the Hand-harvest of October 21.

Distance from Line	Water[1] Applied	ET[2]	Fresh Root[3] Yield	Dry Root Yield	Root Density
m	mm	mm	Mg/ha^{-1}	Mg/ha^{-1}	$roots/m^2$
North					
14.3	372	----	13.9	4.62	61
12.5	436	410	16.4	2.45	34
10.8	526	----	28.7	9.64	82
9.1	623	639	24.6	8.82	35
7.3	683	----	27.1	9.11	87
5.6	767	709	35.8	12.21	45
3.9	927	----	29.2	10.21	70
2.2	1064	941	34.9	11.90	47
South					
2.2	1048	----	29.2	10.35	73
3.9	886	785	27.4	9.44	51
5.6	832	----	30.3	11.00	79
7.3	752	685	18.1	6.53	32
9.1	586	----	18.5	5.99	66
10.8	502	450	12.3	3.76	38
12.5	428	----	9.6	2.78	48
14.3	355	305	7.4	2.36	27

1. Water applied is from planting (5/16) to harvest and includes 104 mm of precipitation.
2. ET = evapotranspiration measured from initial soil water measurements (6/2) and harvest.
3. Yields based on the average of 2, 2.1-m^2 replications from each sub-plot.

equation:

$$Wt. = 10.7 + 0.021w - 0.184n$$

where;

$Wt.$ = average weight per root, g
w = water applied, mm
n = number of roots per m^2

This coefficient of determination for this model was 0.59 and both independent variables (w and n) were highly significant with respect to their effect on Wt. While the average weight per root increased with greater irrigation, it decreased with higher root population. A similar analysis showed that total root mass per area (plot weight) was not affected by root population.

Conclusion

Increased depths of irrigation resulted in increased buffalo gourd root production when grown as an annual, under the conditions described in this study, at a Colorado Plateau site in northwestern New Mexico. The effects of variables such as planting density, planting date, soil fertility, and climate on root production, or the root yield/irrigation relationships of buffalo gourd however, have not yet been determined and further research is required to identify these effects.

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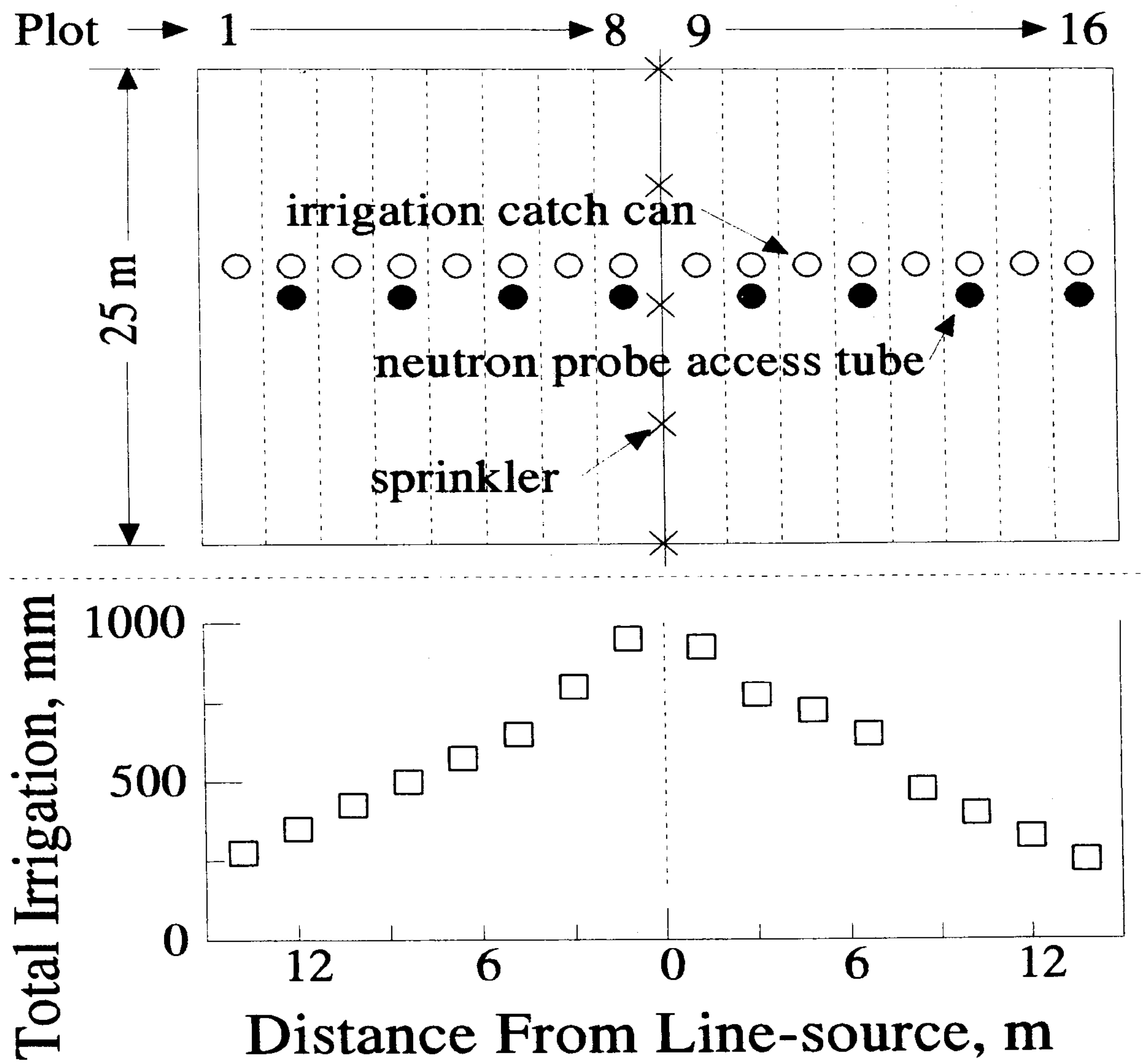

Fig. 1. Diagram of the single sprinkler-line-source plot design used to evaluate buffalo gourd root yield response to irrigation and evapotranspiration, (top) and actual irrigation applied to each plot during season (bottom).

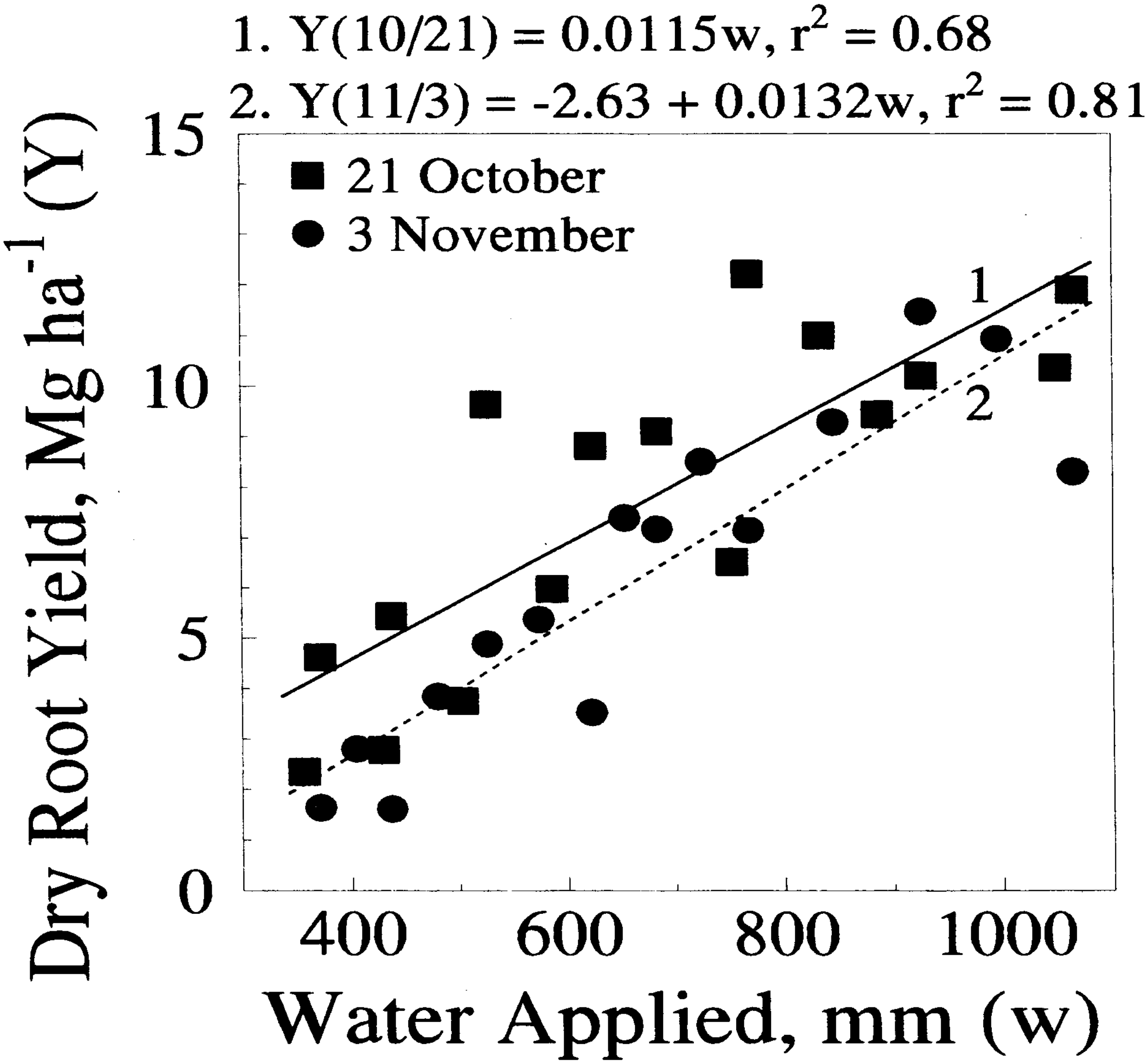

Fig. 2. Mean dry root yield of buffalo gourd, as related to irrigation based on hand harvest of 21 October and machine harvest of 3 November.

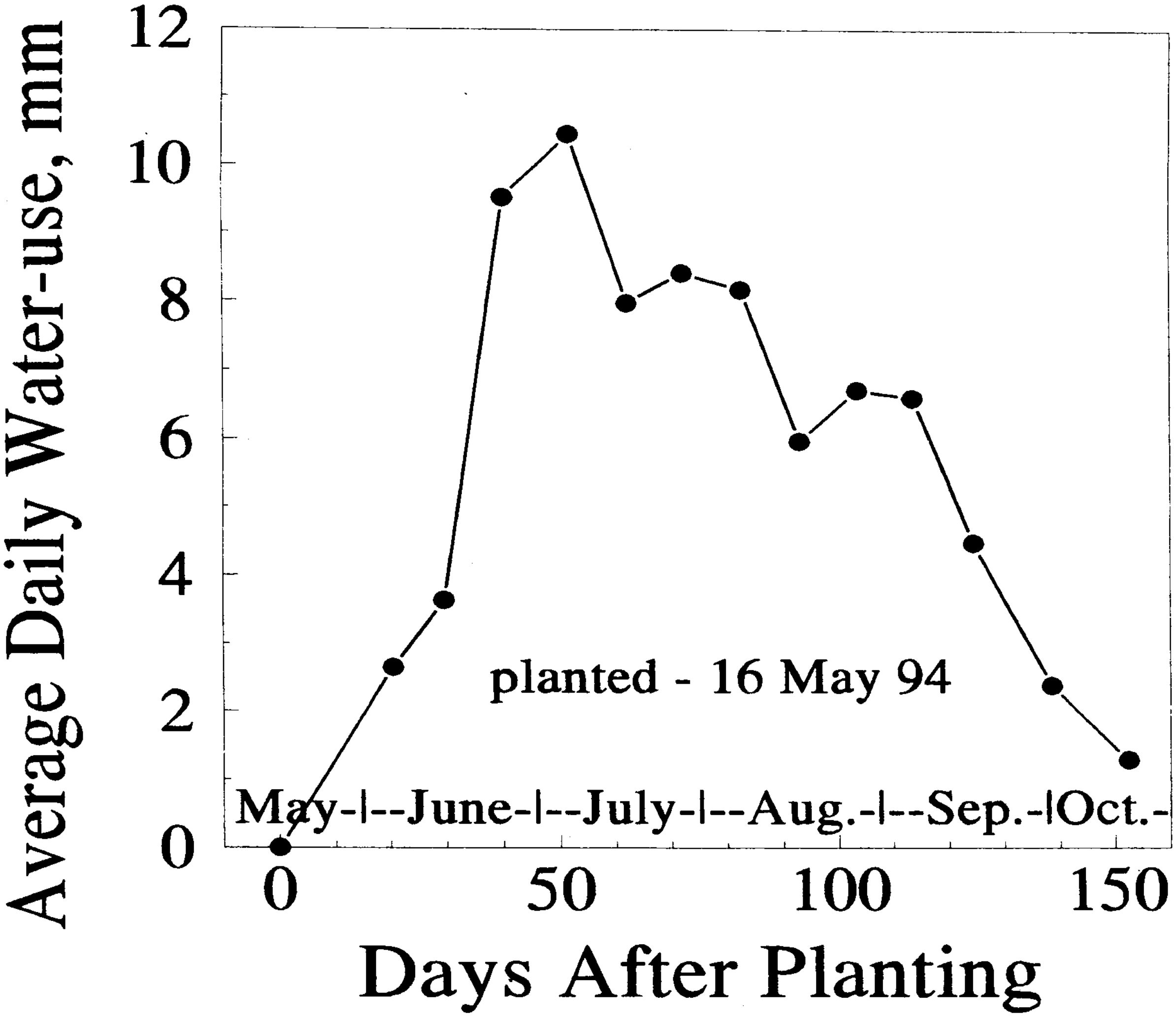

Fig. 3. **Seasonal consumptive-use pattern of buffalo gourd providing a dry root yield of 12.2 Mg ha^{-1}.**

INTRODUCTION OF MISCANTHUS SSP. IN RUSSIA

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Abstract

In terms of the international program on the development of new plants - sources of raw material and biomass, we have been conducting an all-round study of perennial grasses as refurbishable sources of raw materials for fuels and construction industry, and for recultivation of wastelands and technogenically deteriorated landscapes.

Research activity includes:

1. Search of the natural Far East population of Miscanthus and Phragmites ssp. for unique ecotypes and the establishment of an original collection of biodiversity for genetic and breeding work.

2. Development of methods for in vitro cultivation of isolated cells and tissues for inducing polymorphism and salt- and coldresistant somaclones and their micropropagation.

3. To provide the monitoring of the dynamics of potential bioproduction, establishing experimental plantations for Miscanthus in ecologically different terrains of the Novosibirsk Regions.

4. Optimization of waste-free wood processing techniques with respect to Miscanthus biomass (the production of carboxymethyle cellulose and decoration materials).

Introduction

For want of more and more vegetable raw materials as a source of cellulose, man has been heavily decimating forests and is now looking for a substitute to wood.

A tendency in the scientific and research activity towards comparative analysis of many herbs for the rate of biomass formation and for the content of plant fibers as an alternative to wood as new sources of cellulose, fuel, building materials and paper outlined in the mid-80' in countries of both hemispheres, according to the diversity and representativity of the plant communities and the needs in fuels or engineering raw materials.

There is literature evidence that aside from traditionally utilized sugar-cane, corn, bamboo, rice and wheat straw and a range of perennial grasses are of interest, too (Cherney et al., 1986).

Special attention is paid where preliminary estimation is made for the content and quality of the plant fibers in various representatives of the endemic floras in poorly studied and scarcely attainable regions as Mexican deserts and semideserts (McLaughlin, Schuk, 1991), regions in South-Eastern Asia and Far East, tropical forests.

For example, in the flora of Amazonia alone, 49 species with prospects have been uncovered in Poaceae and Malvaceae (Oliveira et al., 1991).

Here is a worldwide rundown on the grasses currently under trials:

China -	Phragmites vulgarae, Sesbania vulgarae are level with ash tree, birch (Guo Ji-tang, 1987; Pan Zhu Chao, 1988), Miscanthus sinensis (Chui, 1993);
Korea -	Arundo donax for cellulose industry, 42.3% cellulose (Kim Chung, 1989; Hong and Son, 1993);
Belgium -	Bromus, Miscanthus (Lambinon J., 1993);
Denmark -	Phragmites, Arundo, Miscanthus (Hansen et al., 1992);
Italy -	Sorghum, Spartum, Hybiscus (Mariani et al., 1989);
England -	Cinara cardunculus, harvested up to 4 kg/m^2 as a source of oil, cellulose pulp, fuel (Fernandes L., 1989), Miscanthus - a perfect culture for fuel;
Germany -	Phragmites, Arundo, Miscanthus (Ei Bassam Nasir et al., 1992; Guth Dietrich 1993);
Spain -	Onopordum nervosum L. (Manzanares et al., 1987);
Sweden -	Salix ssp.;
Russia -	Phragmites, effect of industrial waste waters (Ovchinnikov Yu.B., 1986), hemp as a fiber-bearing plant (Sitnik et al., 1992), miscanthus as a source of cellulose (Godovikova, Shumny, 1993).

Despite so much difference in vegetation, climate and geographical situations, there is a striking coincidence in what is opined over natural species - the most often to mention are vegetatively propagated perennials of the genera Phragmites L. and especially Miscanthus Anders., which is noted for a fast growth and a high tissue concentration of cellulose and beats a lot of trees for specific bioproduction.

Plants of the genus Miscanthus, or informally, eulalia, comes from the Southern Asia, occurring in its tropical and subtropical regions and Pacific islands.

In Russia, two species occur in the Far East, where savanna-like compositions are formed by their grouping with the species of Arundinella and Mulenbergia and the Quercus mongolica (Tsvelev, 1987).

The general name of the genus was given in 1855 by Andersson (1856), and then has been revised by taxonomists who would consider such genera as Imperata, Errianthus, Saccharum, Miscanthus. Taxonomically, Miscanthis is a very complex genus owing to polymorpohism, which causes dispute at any time another individual is to be classified.

The ecological plasticity of miscanthus - its capability of growing in drought and overmoistening, and on the sandy, salty soils allows us to use the plants of this genus not only as a potential source of cellulose, but as a means of recultivation of wastelands.

The problem of rational use, preservation and recultivation of the natural resources, in the first turn soils, asks a complex solution.

Western Siberia occupies 15% of the Russian area and is noted for a high diversity both at the species and ecosystem levels. Its natural features cannot be found elsewhere in Russia (clear-cut continental climate; deep, durable freezing, vast saline lands) plus the anthropogenic effects - all together, these factors make the nature of Siberia more vulnerable, the process of revival slower - owing to which considerable part of Siberian landscape shows signs of degradation, unfortunately irreversible.

Consider Yudinsky Ples (Novosibirsk Region), of which 44.000 km^2 used to be water surface before humans set up a levee between Ples and the lake of Chany - now these square kilometers are covered with the sands of a giant saline land (Fig.1).

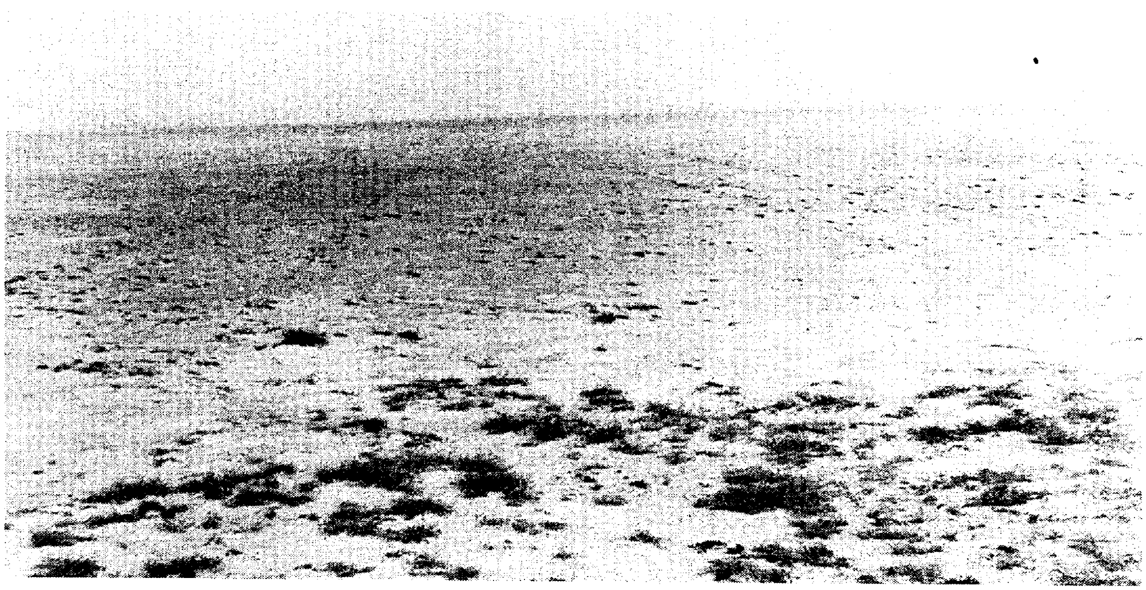

Fig.1 Sandy bed of Chany Lake: a general view.

One of the promising and realistic approaches towards re-cultivation of technogenic and ecologically unfavorable landscapes seems to be introduction of previously irrelevant plants.

Main Goals and Results

Setting Up a Collection for Genotypic Diversity of Miscanthus

Introduction of a new plant implies that original plant material is to be harvested and studied in the natural habitats, and that a diversity collection is to be set up for the species of miscanthus and the accompanying plants in biocoeonoses

Since 1992, we have made two Far East expeditions and covered the area between the north of the Primorsky Kray and the vicinity of Khasan Lake and the Russian-Korean frontier, the result of which is the unique material we gathered: a collection of seeds and initial plants of a range of distinct varieties and ecotypes of two miscanthus species (Fig.2), namely M.purpupascens (Anders) and M.sacchariflorus (Maxim.) related to the family: Poaceae; subfamily: Pooideae; tribe: Andropogoneae.

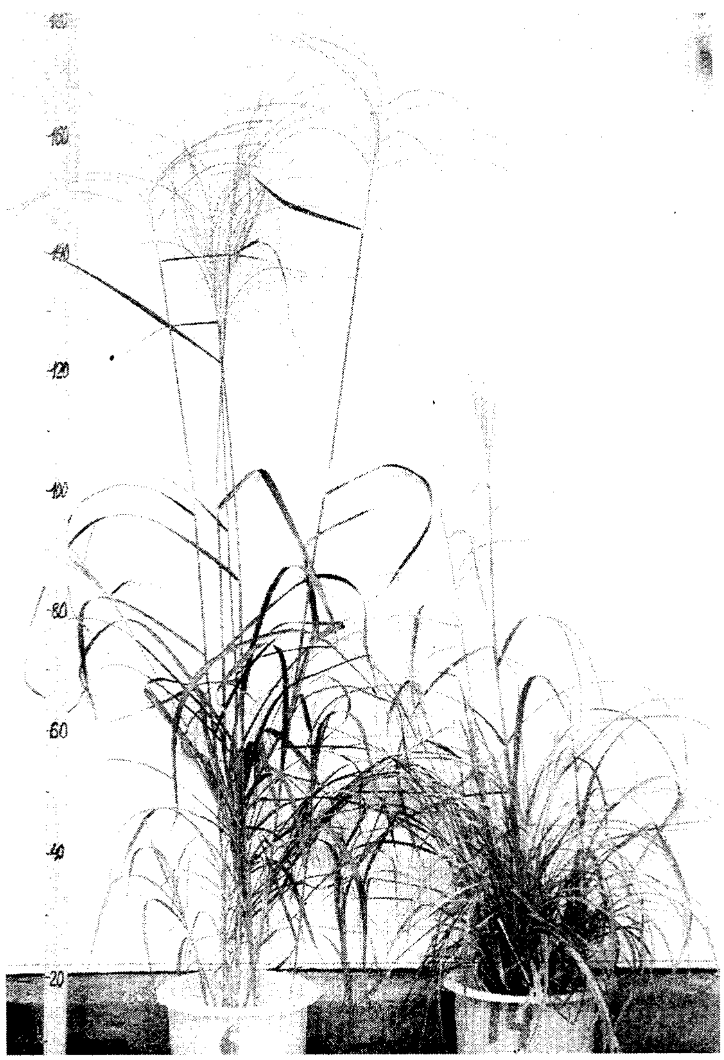

Fig.2 Flowering plants of M.sacchariflorus (left) and M.purpurascens (right)

Miscanthus is a type C-4 perennial plant 0.5 - 3 m in height with an annual cycle of development. 10-12 nodes, nonbranching; leaves are conic - elongated, narrow long up to 50 cm in length and 1.5 - 3 cm in width. Inflorescence is pussy, silvery. Inflorescence branches are either direct or ramifying. Inflorescence has from 5 to 40 branches. Flowering is open, anthers colored (dark red), hanging on long threads. Plenty of pollen. Propagation is mainly vegetative, by rhizomes. Rhizome is either shortened, thick or thin with thin creeping shoots (species character). Seedset is low even in the wild, seeds are black elongated or gray-coated with scarcely developed embryos. The seedlings are highly morphologically heterogeneous.

The high variability of Miscanthus must be also endowed by selfincompatibility (Hirayoshi et al., 1955), as we neither obtained seeds in the field on an experimental plot nor in the greenhouse.Material was described, systematized and transferred to a hydroponic greenhouse and to an experimental station of the Institute of Cytology and Genetics of the Siberian Department of the Russian Academy of Sciences, where, first in Russia, a permanent plantation of miscanthus biodiversity has been laid down. Plants of more than 160 genotypes differing in habitat, duration of the vegetation period, biomass production, cold resistance and other parameters are growing on 1.5m x 1m plots.

Although the mean absolute lowest annual ambient temperatures are different in Far East and Novosibirsk (the difference is 17^0C), winters are heavier in snow and harsher - all the plant material has well adapted itself for past three years, which allowed the conduct of genetic and breeding work on selection not only for bioproduction and cellulose content for future development of resistant rechargeable resources of phytobiomass, but also for the most unpretentious forms with which to resolve a range of ecological problems. In 1994, two experimental plantations were laid down on the sands on the dry floodlands of Chany Lake in the Novosibirsk Region.

Comparative biometrical data on the main indices in some available clones are presented in the following table:

genotype	height, m	max. diametre, m^{-2}	Biomass production, kg/m^2	
			fresh	dry
M.pur.3a	0.60	3.0	0.28	0.11
M.pur.4	1.20	3.2	0.24	0.13
M.sac.5	1.30	5.2	0.58	0.26
Var.1	1.50	4.2	0.41	0.19
Var.2	1.25	4.0	0.36	0.15
M.sac.9	1.38	5.3	0.62	0.29
M.sac.10	1.43	5.8	0.80	0.36
M.sac.11	1.85	6.8	1.60	0.58
M.sac.12	1.63	8.0	1.08	0.46
M.sac.13	1.70	5.1	1.30	0.42
M.sac.14	1.62	6.3	1.10	0.41
M.sac.15	1.34	5.2	0.70	0.33
M.sac.16	1.20	4.7	1.10	0.22

In vitro cultivation of isolated cells and tissues of Miscanthus

An utterly poor seed yield, endemy, and difficult ways for obtaining seedlings from vegetative propagation represent a problem for immediate introduction of Miscanthus into agricultural practice. Methods are therefore required for in vitro cultivation of isolated cells and tissues for producing somaclones, salt- and cold-resistant forms and for their microcloninig on a semicommercial scale.

Part of the most interesting ecotypes was taken into in vivo culture (Fig.3).

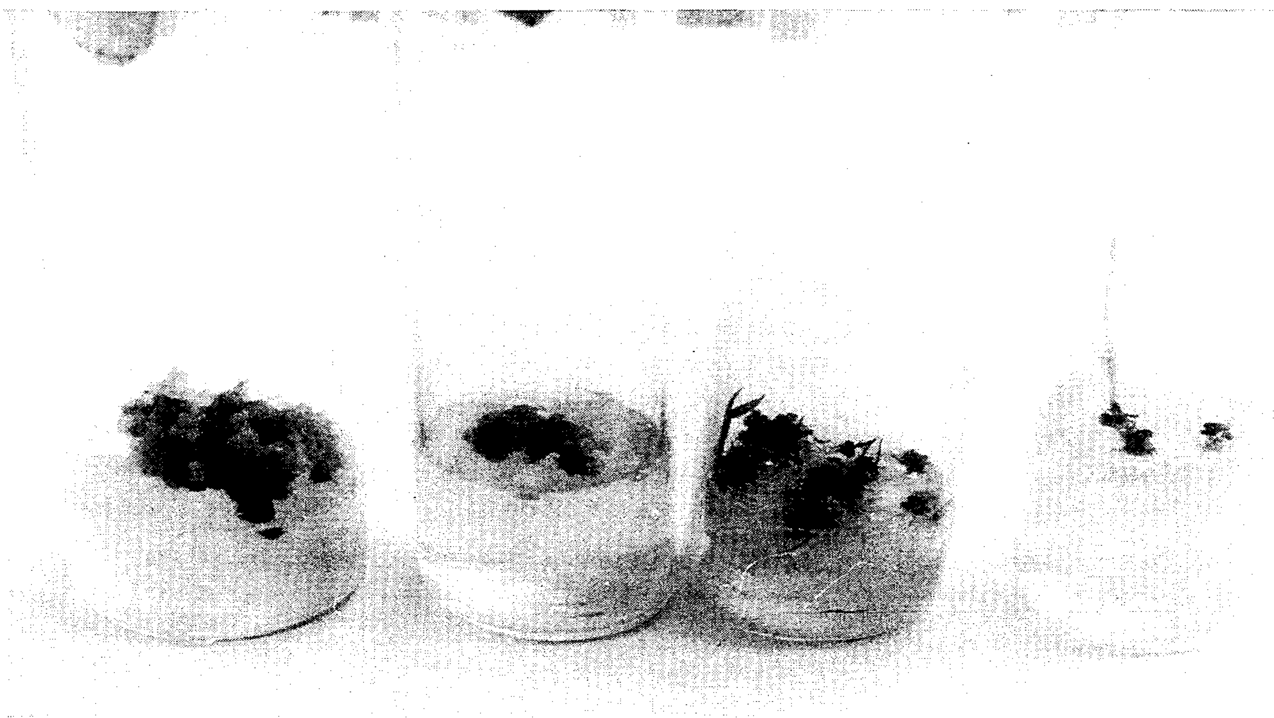

Fig.3 In vitro cultivation of isolated cells and tissues of M.sacchariflorus on different media and development of regenerant plants.

As an explant, we took the apical and nodular meristems of vegetative stems and immature inflorescence of plants grown in the hydroponic greenhouse.

Murashige and Skoog medium was the basic with an addition of Gamborg's vitamins and 2,4-D as a phytohormone in varying concentrations (2-10 mg/l). The frequency of callogenesis was low (30%) and was not dependent on which type the explant was.

The best type of explant for production of embryogenic callus and obtaining plants regenerants was the apical meristem and immature inflorescence. The resulting plants were transferred to soil. Morphological and cytological analysis is in progress.

Joint Investigation and Scientific Contacts

In cooperation with the Altai State University, we have started investigations into waste-free processing of Miscathus biomass as a source of carboxymethyle cellulose and ecologically safe decorative building materials.

Negotiations over possible joint programs on cloning and introduction of Miscanthus species into agricultural practice between our Institute and the scientific teams from Denmark and Germany are currently on.

Conclusion

After we performed this portion of study of the plants of the genus Miscanthus, we have ensured that the plants are really worthwhile in two respects - the continuance of the study and funds for it. The plants will be useful as:

a refurbishable source of raw materials and building industry (before the 30'th, a small cardboard factory used to work on reed grasses);

a means of resolving a range of ecological problems of recultivation;

a fodder grasses in agriculture.

CELL AND TISSUE CULTURE OF MISCANTHUS SACCHARIFLORUS

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Abstract

Since recent time search and introduction of new species of plants have paid attention. More perspective are perennial low maintenance landscape plants from genera Phragmites L. and Miscanthus Anderss. known as high speed growing and great amount of cellulose's containing.

Absence of seeds production and limited distribution area prevent from immediately introduction the plants of this species

The main goal of our investigation is the scientific development of the cell and tissue culture methods to get changing clones, salt and cold tolerant plants and their micropogation.

At present there are collection of biovariety represented by subspecies, ecotypes and plant regenerants of two species - Miscanthus purpurascens (Anders.) and Miscanthus sacchariflorus (Maxim.)

Successful results have been achieved in screening of culture media, prepared on MS base medium and contained a row of tropic components to protect the explant and callus tissue from oxidation and necrosis.

Initially the callus was induced from stem segments, apical and nodular meristem of vegetative shoots of elulalia, growing in hydroponic greenhouse.

Morphological and cytologic analysis of plant-regenerants have be done.

Material and Methods

All plant material was pick up, classified and described during two Far East expeditions in 1991-1992 years. There are several ecotypes of two endemic species of genus Miscanthus - Miscanthus purpurascens (Anders.) and Miscanthus sacchariflorus (Maxim.) Benth., belong to tribe Andropogoneae, family Poaceae.

For cell and tissue culture the plants from hydroponic greenhouse were used. The plants with 5 - 7 nodes were the best for explant taking. Apical and nodal meristems and immature inflorescence were used as explant.

Surfers sterilization was done in the follow way:

- 1 min in 70% ethanol,
- 3-5 min in 10% chloramine solution in special tubes for vacuum infiltration,
- 3 times rinse in distillation water.

After sterilization nodes were cutting far and wide into 4 parts and placed on media by inner side.

For receiving of "baby"-clones sleeping node's buds were used.

The base MS media (Murashige & Scoog,1962), supplied with Gamborg's vitamins, 250mg/l hydrolyze casein, 10 mg/l proline, 100 mg/l inositol, 1mg/l nitrate, 1mg/l ascorbic acid, 1 mg/l pantotenate calcium, 20 % saccharose and 7% agar was used. pH was adjusted to 5,8 before autoclaving with NaOH.

Media differ by phytohormone contents:

1 - for callus induction with 2,4-D (3-5mg/l)
2 - for growing callus with 2 mg/l 2,4-D and 0,1mg/l kinetin;
3 - for initiation of regeneration process and "baby"-clones without phytohormones.

Cytogenetic study of pollen fertility was be done under light microscope after staining of pollen corn with acetocarmine.

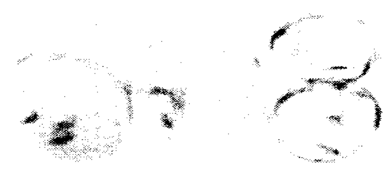
Results and Discussion

Comparative biometric data concerned habits and fertility of two species of Miscanthus are demonstrated in Table.1:

Characteristics	M.sacchariflorus	M. purpurascens
Height, m^{-2}	145.7 ± 8.81	96.7 ± 1.2
Shoots, number		
vegetative	7.3 ± 1.1	6.0 ± 3.5
generative	2.9 ± 0.4	10.7 ± 2.4
Inflorescence, m^{-2}	27.8 ± 0.4	21.6 ± 2.3
Fresh weight, kg^{-3}	106.7 ± 11.7	66.7 ± 14.5
Pollen fertility, %%	94.3 ± 1.1	85.3 ± 2.4

In spite of high level of fertility of pollen (Fig.1) with well expressed 2 generative and one vegetative nuclei we could not receive any one seed.

Figure.1. Pollen grain after staining in acetocarmine:
a - 2 generative nuclei;
b - vegetative nucleus;
c - abnormal pollen.



This phenomenon could be explained both high extent of self-incompatibility (Hirayoshi et al.,1955) and amphydiploid nature of Miscanthus because by high base number of chromosomes n=19 (Adati & Shiotani,1962),.

Well crossing Miscanthus with Saccharum (Li et al., 1961) and partial homology and existence of some join unique restrict sites of nucleus r-DNA with Errianthus (Glasman et al., 1990) confirm hypotheses of hybrid origin.

More over cytologic analysis, prepared by Linde-Laursen in 1993 showed that wide using in West Europe Miscanthus giganteus is the complex sterile interspecies hybrid.

Certainly, propagation through seed is unreliable on account of low viability and extreme poor seed-set.

In vitro culture investigation was be done on two base directions (Figure.2).

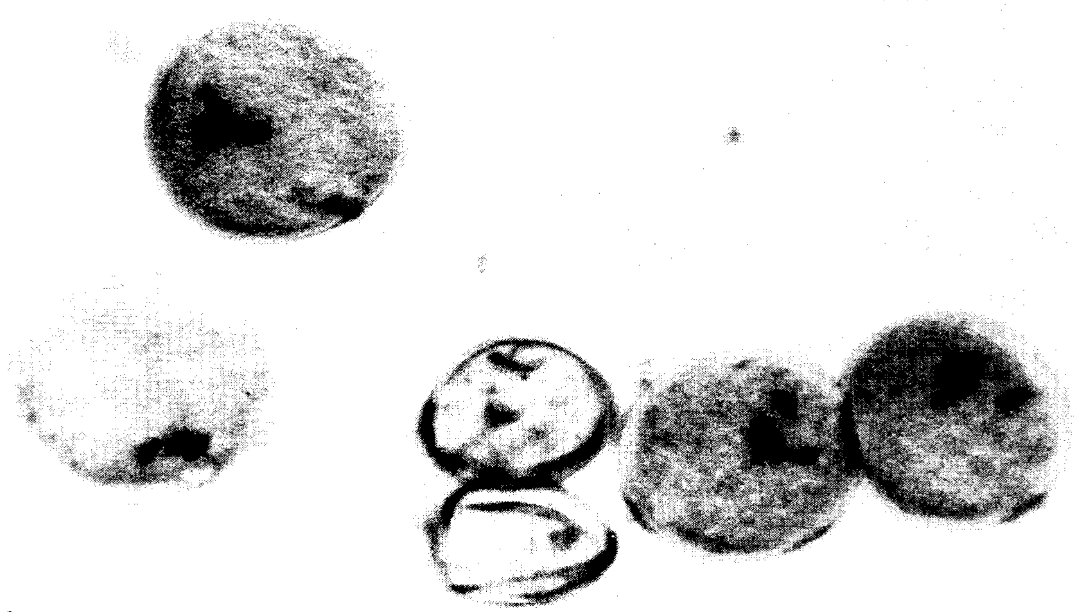
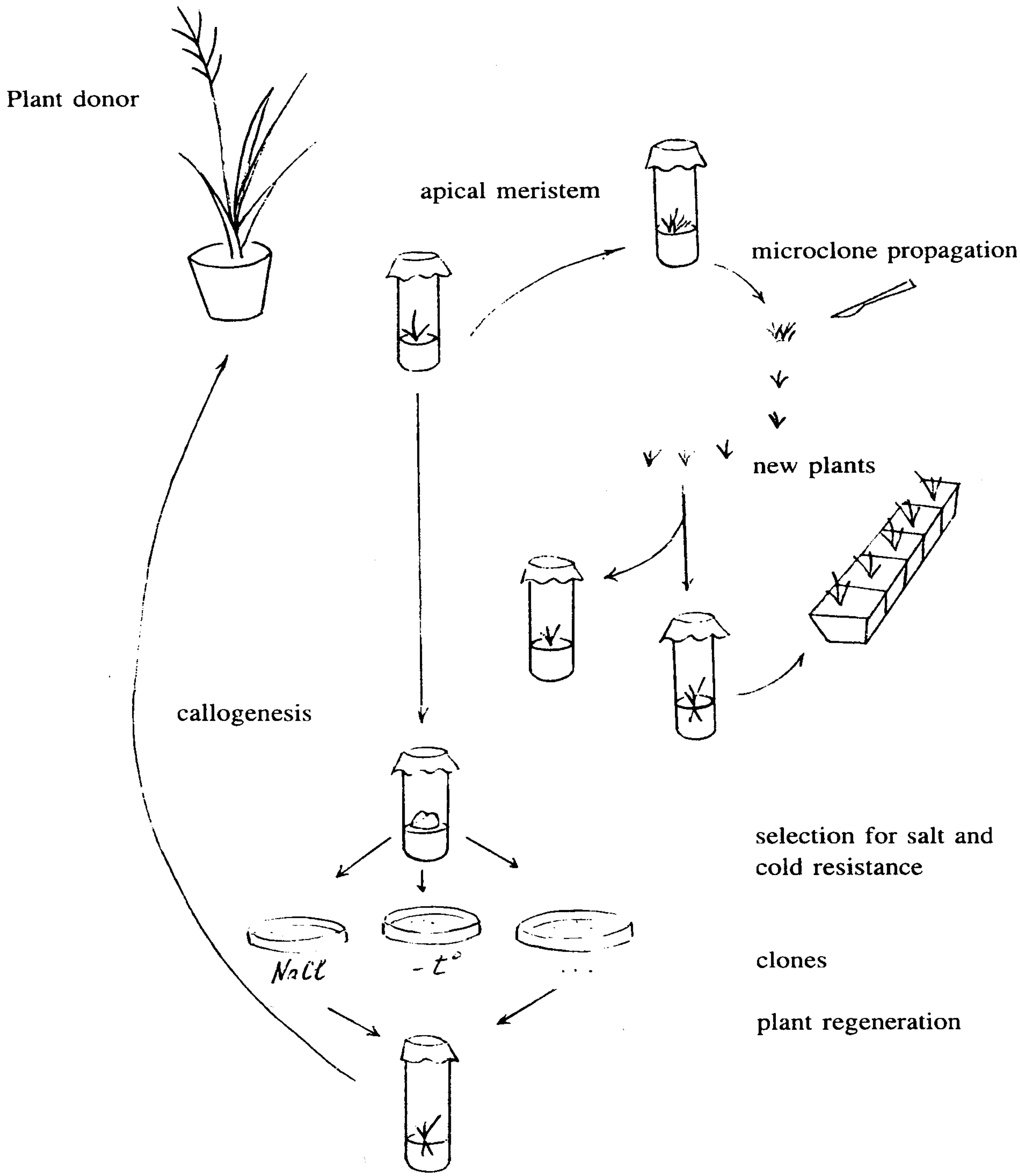


Fig.2. In vitro Technique of Cell and Tissue Culture and Plant Regeneration of Miscanthus ssp.



1. Receiving long term morphogenic or embryogenic callus or suspension culture for induction of regeneration process and production of plenty regenerants. On this stage of investigation we plan conducting the cell selection on cold- and salt tolerances for getting new resistant clones of Miscanthus.

2. Working out an efficient and rapid method of in vitro micro clone propagation for producing of health and similar seedlings in enough quantity. After screening of generally accepted for cereals cell cultivation's media we try to induce primary callus, but at the first time in all using media acute browning of explant and culture medium were begun and after 5-7 days necrosis of plant tissue was observed.

As a rule, browning of media is induced by phenols. Usually for preservation of explant tissue adding in media some adsorbents, such as active coal, or often passages on fresh medium are used (Gawell et al., 1990).

In our case the best results was achieved by adding antioxidant mixture of ascorbic and citric acids, as well as 10 mg/l proline.

Study of influence of 2,4-D in different concentrations on callogenesis showed that the best level of phytohormone is 3-5 mg/l.

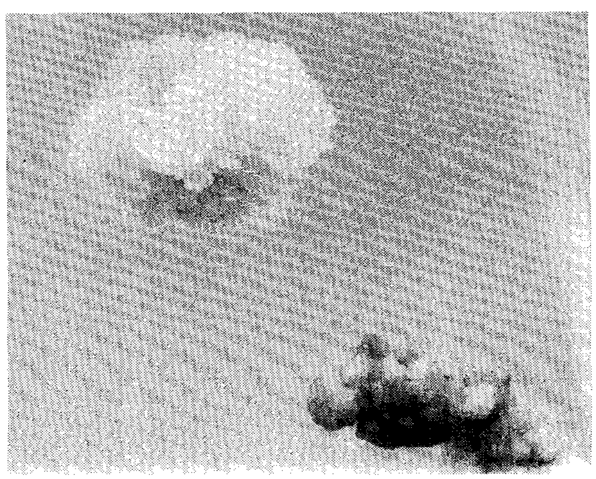
The frequency of callogenesis was low (less 30%) and did not depend on type of explant - all nodes in spite of position, apical meristem, immature inflorescences and anthers were totipotent. Induction of callus depend on physiological condition of explant, especially from age.

The callus growing was too low and there was polymorphism in calli types.

After phenotype and histology analysis of callus tissue 5 type of calli differing by color, consistence, density, size and viability of cells and especially by organogenic activity were observed.

So, among the primary formed calli two base types were characterized (Fig.3):

Figure.3. Two different types of primary calli.



-slimy, soft, semiclean callus with heterogenic forms of cells;
-firm, white or yellow color callus with global structure crushed on small pieces under pincer.

Callus of 1 type produce during cultivation 3 kind of calli:

-semiclean with large cells nonembriogenic;
-semiclean with chlorophyll or anthocyanin colored pots;
-soft, watery with root structure;

Callus of 2 type differed on two kind:

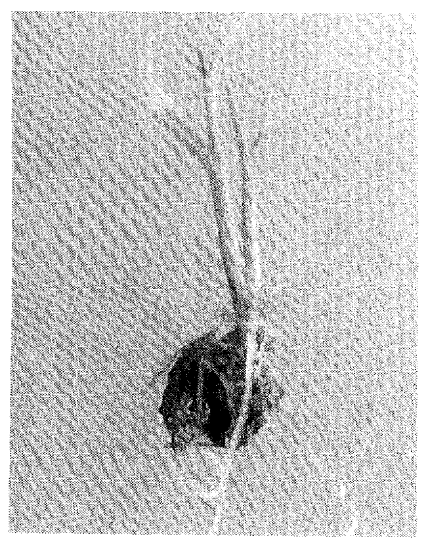
-firm, smooth surface, white with green or anthocyanin colored areas;
-semisoft, white, nodular. with embriolike structures.

After transferring the 2 type of calli on phytohormone free medium plant regeneration was observed.(Fig.4).

Figure.4. Appearing of meristemic shoot primordia

When shoots had formed three to four roots in vitro, they were transferred to potting soil.

Figure.5. Plant-repenerant of M. sacchariflorus.



Level of propagation is for 15-20 plants on explant and depend on fast loosing of embriogenic ability so typically for cereals, as well as some difficulties in culturing of Miscanthus especially because high necrosis of callus tissue.
Received plant-regenerants are differed in total height from parent's plants.(Table.2).

Table.2. Comparative characteristics of some plant regenerants, growing in glasshouse during two vegetation.

Genotype	Height, m^{-2}	Max straw ⌀, m^{-2}	Nodes, qty	Leaves, qty
M.sacchariflorus	116.2 ± 5.3	5.1 ± 0.3	8.6 ± 0.4	10.6 ± 0.3
R1	152.0 ± 23.3	4.3 ± 0.4	11.3 ± 1.8	13.9 ± 0.7
R2	195.0 ± 12.3	6.0 ± 0.3	14.3 ± 0.5	14.7 ± 0.4
R3	227.2 ± 9.8	5.0 ± 0.3	19.0 ± 1.3	21.2 ± 1.2
M.purpurascens	31.0 ± 0.6	2.7 ± 0.3	2.3 ± 0.3	5.0 ± 0.6
M-R1	224.4 ± 5.7	5.1 ± 0.3	19.1 ± 1.3	22.8 ± 1.9
M-R2	191.9 ±16.7	5.1 ± 0.5	13.6 ± 0.2	15.0 ±0.7

Preliminary cytologic analysis of chromosome numbers of parent and plant-regenerants showed the same chromosome set n=38.

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PRIORITIES FOR ECOLOGICAL RESEARCH ON ENERGY CROPS IN THE NORTH CENTRAL STATES

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Abstract

Following the principles set by the National Biofuels Roundtable, a workshop was held in March, 1995 which brought together a group of stakeholders and experts in the field of biomass energy and ecology. The mission of the workshop was to identify and set priorities for ecological research to ensure that large-scale biomass energy development in the North Central states occurs in an ecologically sound, sustainable manner. The workshop found that questions about the landscape-scale deployment of biomass plantations were most pressing. The workshop recommended that adaptive resource management principles be applied in a phased development of increasingly larger plantations. Each phase of development would help to answer questions about landscape-scale development; improving the design of subsequent phases. Principles of sustainable agriculture should also be applied to biomass plantations to minimize impact on soils and water quality, maintain productivity and benefit the rural economy. Results of the workshop will be helpful to natural resource and research agencies, as well as utilities and biomass energy developers.

Introduction[1]

One of the barriers to wider development of biomass energy sources is the lack of information about the environmental impacts of deploying biomass crops on a landscape scale. The National Biofuels Roundtable (1994) recognized this in developing its broad guidelines for application nationwide. These would have to be adapted to fit the dynamics of any particular region. The North Central States, including Minnesota, Wisconsin, Michigan, Iowa, and Illinois, have been identified as having great potential for developing biomass energy sources (Union of Concerned Scientists, 1993). Advocates of biomass energy have recognized that a multidisciplinary approach is needed to produce an acceptable plan for developing biomass energy in the region.

To that end, a steering committee of major stakeholders and research institutions sponsored a workshop to develop an agenda for biomass energy ecological research in the region. The workshop brought together speakers and stakeholders from the important disciplines to suggest what research will be needed to answer concerns about the environmental impacts of large-scale energy plantations. This paper summarizes the major themes of the presentations and the discussions held by the participants.

Presentations

Full Fuel Cycle Impacts of Energy Technologies[2]

Conventional generation of electric power imposes a significant toll upon the environment, from all aspects of the fuel cycle. Extraction of coal, oil, natural gas and uranium disrupts the environment where they are found. Transporting these fuels sometimes requires the construction of roads, railroads, pipelines and other facilities, and the consumption of fuel to move them. Power plants themselves disrupt the environment, and the transmission lines that move the electricity also have their impacts. Finally, the emissions and discharges produced as by-products of generation cause their own pollution and environmental degradation.

In contrast, producing biomass fuels can be relatively benign, depending on the source of fuels. Using industrial and urban wood residues can help solve solid waste disposal problems. Growing plantation crops on current farmland produces no more,

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[1]The Workshop was funded by The National Renewable Energy Laboratory, Wisconsin Electric Utilities, Minnesota Power, Electric Power Research Institute, Oak Ridge National Laboratory - Biofuels Development Program and The Great Lakes Regional Biomass Energy Program

[2]Presenters: James Cook; National Audubon Soc., Whenonah Hauter & Paul Jeffries, Union of Concerned Scientists

and often less environmental damage than conventional crops. Transportation distances are shorter, so less fuel is consumed. Conventional and toxic pollutants are equal to, or less than, natural gas due to low sulfur and metals concentrations.

Greenhouse gas emissions can be minimized using biomass, especially with closed-loop plantation systems. With planting to replace consumed fuel resources, equalization could be possible. At least, biomass cycles "contemporary" carbon, rather than releasing fossil carbon.

Sustainable Agriculture and Energy Crops[3]

Sustainable agriculture seeks to maintain the productivity of agricultural systems by using cultural methods which minimize the use of chemicals and energy to sustain production. At the same time sustainable agriculture attempts to maximize the recycling of organic matter and natural fertilizers. Sustainable practices attempt to retain the soils, reducing runoff and pollution of water bodies.

Defining agricultural sustainability is subjective, but extractive agricultures are always ecologically unsound. The "highest use" for a farm's land must take into account the farm's economics, the environment of which it is a part, and the social value of keeping people living on the land. Time scale is important: long-term soil productivity, for instance, and long-term avoidance of "boom & bust" economic fluctuations.

Woody or herbaceous biomass can diversify the farmer's income mix. This gives the farmer flexibility in fluctuating economic conditions, helping to keep the farm profitable and intact. Biomass crops can be planted on marginal lands that require vegetative cover for critical periods, or would otherwise provide very little or no income without significant ecological damage. They can allow the farm to support a wider variety of wildlife and protect against soil erosion and nonpoint water pollution.

The amount of energy that the biomass fuel provides must exceed that used to produce it. Species and varieties utilized must be adapted to the local cropping conditions and fit into the farm work schedule over the year. Breeding for higher yields should not be at the expense of pest tolerance and local soil and climate adaptations. Nutrient budgets, including the ash from crop combustion, must be computed and soils tested to minimize the use of imported fertilizer.

Harvest must be timed to allow the farm to protect important wildlife species and to reduce soil erosion and nonpoint pollution. Leaving residues on the fields can protect against soil erosion and preserve soil texture. A market and cash flow must be guaranteed to reduce the risk for the farmer and allow the farmer the profitability required to think long-term. Regional planning, monitoring and research to determine impacts and causes would be needed to optimize placement of biomass crops in the landscape.

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[3]Presenters: Dennis Keeney, Leopold Institute; Bill Berguson, NRRI; Wendell Johnson, Univ. of Minnesota; & Jerry Hatfield, National Soil Tilth Inst.

For example, biomass crops would grow well on Conservation Reserve Program (CRP) lands and would provide the protection that they need in addition to the income that the farmer needs. Biomass crops could also be planted as buffer strips or filter strips or in drainageways to protect surface waters from nonpoint fertilizer and herbicide pollution.

Concepts and Principles of Landscape Ecological Planning[4]

Landscape Ecological Planning is a tool to integrate resource use with biological sustainability. The scale of thinking has to be different - ecosystems, rather than populations or species. Processes and natural fluctuations have to be taken into account, and multiple scales of space and time must be considered.

One approach is to look at the systems present, define the stresses on those systems, and their sources, evaluate strategies to relieve those stresses, and build on already successful approaches.

The original and existing landscape features, vegetation patterns, soils, and hydrology, of an area will suggest patterns and uses that can succeed there. For example, grasslands and row crops could be the basis of plantation management in the Southern portion of Wisconsin, which was once dominated by prairies and oak savannahs. In the North, where forests mixed with wetlands and lakes were dominant woody species may be appropriate. In the ecological tension zone that crosses Wisconsin from northwest to southeast, a pattern of interspersed grassy and woody crops would be desirable.

In looking at the sizes of plantations, lessons from studies of habitat patches can be useful. These too have to be considered in the context of the larger landscape. Patch design and interspersion have to be considered in relation to defined resource needs and explicit ecological goals: How many patches in a unit area? How far apart? Can they be contiguous with existing forests, grasslands, waterways or other ecological features? Do composition and arrangement hinder or promote stated needs and goals.

Finally, it is important to inventory the resources present at each stage of development, and to monitor processes as they develop. Constant assessment is needed both to successfully manage on a landscape basis and to inform future projects.

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[4]Presenters: John Probst, U.S. Forest Service - No. Central Forest Expt. Station; & Andrew Schiller, Oak Ridge National Lab.

Adaptive Resource Management Approaches to Research[5]

Adaptive Resource Management attempts to combine research and policy making. It recognizes that change is inevitable, systems are too complex and dynamic to easily predict the effects of management decisions, but that decisions must be made before complete understanding is achieved. Each policy is itself a hypothesis about how a system will respond. Thus it can be tested, and modified to account for what happened in the real world. This knowledge can then be applied to the next decision, hopefully improving its effectiveness.

It is important to test hypotheses that reveal trade-offs between alternative land uses under biomass energy scenarios. Would increased demand for biomass fuels result in the conversion of marginal lands? Would the impacts be the same, more, or less than leaving those lands to natural restoration processes? Adaptive Resource Management approaches would allow these questions to be investigated concurrent with the scale-up of biomass plantations.

A collaborative approach among stakeholders can muster the resources needed to carry out the necessary research. Current ecological studies in Minnesota and Iowa exemplify this method. Comparisons of bird species diversity parameters between plantations, natural forests, and croplands are helping to refine basic hypotheses such as: "Bird diversity and presence of forest-interior birds in plantation interiors is lower than woodlands of similar size but higher than in most agricultural crops and pastureland".

The results should help to design plantation layouts that maximize the potential habitat value of energy plantations.

Ecological Lessons and Implications for Large Scale-Up Projects[6]

Experience from studies of existing small scale plantations, and from similar production systems can point out opportunities and pitfalls for attempts to develop biomass plantations on a large commercial scale.

Studies of bird and small mammal populations indicate that plantations will be ecologically intermediate between woodlands and croplands. Landscape context, patchiness and size are important factors. Further research is needed to refine these indications and develop predictive capacity.

Reducing soil erosion and resulting water pollution, especially on highly erodible lands, should be an important direction for demonstration and research. Methods of cropping that both reduce the need for fertilizers and pesticides, and retain soil should

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[5]Presenters: Tom Nudds, Univ. of Guleph; Christine Ribic, Univ. of Wisconsin; & James Cook, Nat'l Audubon Soc.

[6]Presenters: Don Christian, Univ. of Minnesota-Duluth; Arthur Petersen, Univ. of Wisconsin-Madison; Tom Houghtaling, Minnesota Power; & Eric Vance, NCASI

be tested. Alternative nutrient sources such as sewage sludge (biosolids) may be useful.

The balance between environmental protection and economics should also be considered. Landowner rights and preferences have to be accounted for in designing plantation systems. The economic and social costs of alternative management practices need to be acknowledged.

Experience from the pulp and paper industry has shown that intensive management can be compatible with environmental quality. Following Best Management Practices for erosion control, such as leaving buffer zones along waterways, can protect water quality. Landscape-level analyses of biomass crop development will facilitate preserving or enhancing the environmental values of adjacent lands. Using alternative soil amendments could maintain soil structure and fertility.

Discussion Results - Research Priorities

Three work groups were given instructions to identify needs, priorities and implementation steps for the following research topics: 1)Ecological Research; 2) Environmental Quality Research; 3) Agricultural Sustainability Research; and 4) Policy Requirements to Support Research. Group facilitators directed the discussions in each group to try to elicit the most involvement, and reflect perspectives from all of the stakeholders participating in the Workshop.

Each group reported the results of their discussion to the participants. The Steering Committee then organized the recommendations into topic areas. These are presented below. Priorities were not explicitly set by all of the work groups, but these issues came up several times in discussions, and most groups made similar recommendations.

Landscape Issues and Biological Studies

Investigate the effects of placing biomass crops in the landscape. Attempt to enhance patterns and features already present. Develop siting guidelines to maximize benefits and minimize disruptions. Develop tools to assess and predict water quality impacts of siting strategies. Develop Best Management Practices (BMP) for all plantation crops, at all spatial scales. Develop protocols to match crops to sites. Study options for the use of short rotation woody crops (SRWC) and herbaceous energy crops (HEC) in riparian areas.

Study the role of habitat inclusions within plantations, both in terms of wildlife and economics. Determine location and structural features of planting that maximize habitat values. What is the optimum shape and arrangement of stands (blocks vs. corridors, size & number) for given species and species mixes? Investigate the benefits of heterogeneity in plantings (vs. monotypes). Establish a desired state (goal) for the landscape, including visual as well as biological aspects.

Set priorities for species of concern: 1. Protected (threatened & endangered) species 2. Local interest species. Gather data on occurrence and distribution, and design landscape-scale studies. Investigate wildlife source-sink relationships in herbaceous and woody crops.

Production Practices

Establish impacts of nutrient and herbicide application on poplars and grasses, soils and water quality. Research and develop methods to minimize short and long term chemical inputs. Transfer experience and knowledge of pulp and paper industry to energy plantations. Study trade-offs between residue left on ground, use of cover crops, and productivity of energy crops. Evaluate harvest cycle impacts on nutrient cycling, soils, wildlife. Investigate the use of biosolids (sewage sludge) as fertilizer. Study effects of alley cropping, strip intercropping. Determine erosion characteristics of different cultural methods.

Evaluate genetic improvement of plant stocks, including disease resistance and yield (selection, crosses, genetic engineering). Investigate potential of other native warm season grasses, forbs and mixes. What is the most efficient way to replace organic matter and nutrients removed in harvest to sustain productivity and maintain environmental quality?

Global Issues

Impacts of energy farming on carbon sequestration.

Research Methods

Assuming an adaptive resource management approach, investigators need to clearly specify the null hypothesis, and design experiments to provide adequate statistical power to reject it. Investigate "dose-response" relationships of alternative management approaches and habitat effects, emissions, etc. to develop predictive capabilities.

Establish institutional cooperation for research funding & implementation, and coordinate agendas among stakeholders. May include alternative users (eg: fiber) in research implementation.

Coordination and Planning

There is a need for up-front proactive involvement of all stakeholders in project planning, design, etc. Include industrial, research, agricultural interests.
Study public perceptions at start and during projects. Carry out social, economic and demographic studies of landowners. Investigate the balance between the environment and economics.

Evaluate Conservation Reserve Program (CRP), commodity programs, etc. for biomass production opportunities. Try contract payments or other financial methods to establish farm cash flows from energy crops. Identify the customers for energy/fiber crops. How do we relate human dimensions and value judgements?

Research integrating biomass crops into existing farm systems. Use whole-farm case studies, demonstrations, education. How can these large scale supply/conversion demonstrations be encouraged, & supported?

Fuel Cycle Related

Study storage issues. Establish transportation impacts. Study air pollutant emissions including toxics from combustion technologies. Establish the effects of management practices on the energy balance of these crops. What are the net energy balances?

Agricultural Sustainability

Establish a definition of sustainability which includes:
- Economics of rural development
- Energy
- Ecological/biological aspects

What are the break even decisions that producers make? What are the multiplier effects? How do domestic and international trade fit in?

Implementation

There is a need to develop an overall strategy, or strategies to focus research and development. What are the policy drivers for research? Develop collaboratives and coalitions to leverage resources and support in uncertain times. Establish communication, domestically and internationally, of research needs and results. Use the Utility Biomass Energy Commercialization Association to encourage utility promotion of biomass.

Education should be a component, for the general public as well as the farm community. Needs and priorities - Factors include stability, development of a broad group of potential feedstocks, coordinating policy under agriculture, economics, energy and the environment. Determine relevant levels of government for each type of activity (local - state - federal - international). Include public and private sectors. Define barriers to entry into the industry, focus on information needed to overcome them.

Summary

Biomass energy development has great potential for reducing the life-cycle impacts of our energy production system. We are early enough in the deployment of these technologies to direct them in an ecologically sound, sustainable manner. Applying the principles of sustainable agriculture and landscape ecological planning are an important part of this process. Many questions about ecological impacts need to be answered, but there is no need to wait until the component elements have been researched one by one. Applying an adaptive research management framework will allow the research to proceed along with deployment by establishing a feedback loop between research, policy and development.

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THE CONSORTIUM FOR PLANT BIOTECHNOLOGY RESEARCH, INC.

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Abstract

The Consortium for Plant Biotechnology Research (CPBR) is a model partnership of universities, industry, and federal laboratories. The CPBR was organized in the U.S. for the purpose of carrying out industrially relevant research and technology transfer. Formed in 1985, it has become a national organization which now includes more than 30 companies and trade associations, 25 universities, and several federal laboratories. Many of the U.S.-based member companies are subsidiaries of parent companies that operate internationally. Using a unique competitive process which includes industrial review for relevance and peer review for scientific merit, the CPBR has sponsored nearly 150 research projects in energy from biomass and plant biotechnology which are resulting in significant industrial gains. Research areas include commercial applications of biomass production and conversion with applications to biofuels, biomass power, and environmental improvement and remediation. The CPBR process promotes equal cost-sharing by government and the private sector for the costs of the research. Benefits of CPBR research are leading to significant corporate investments beyond the research costs to bring the results of the research discoveries to the marketplace. The CPBR is currently seeking international partners through interested governmental agencies and other organizations to foster and fund collaborations between international scientists and engineers in both industry and academe.

Overview

The Consortium for Plant Biotechnology Research, Inc. ("CPBR") links world class university research to industrial needs to encourage the rapid development of new products and processes.

The CPBR supports biotechnology research and technology transfer by fostering and funding research partnerships among academic, federal laboratory, and industrial scientists and engineers. Consortium membership includes 25 universities, more than 30 companies and trade associations, and affiliations with several national laboratories. Industrial participation in the CPBR includes the chemical, agrochemical, seed, forestry, pulp and paper, energy, pharmaceutical, food and other non-food agricultural product industries.

The CPBR's research focus has expanded beyond food and agriculture to include energy, healthcare, the environment and other areas of biotechnology research. CPBR research projects support the development of new and improved products and processes and work to solve industrial problems. Some research goals include reducing the cost of production, transportation and storage of materials; improving the nutritional content of foods and feedstocks; increasing the value of byproducts in common manufacturing processes; and developing industrial capabilities that are safer for the environment.

CPBR's Mission

The Consortium for Plant Biotechnology Research, Inc. brings together U.S.-based industries, universities, and federal laboratories that recognize the need for research and practical industrial applications of biotechnology. The CPBR's purposes are to: (1) promote biotechnology research in fields including food and agriculture, healthcare, energy, and the environment; (2) advance technological innovations to facilitate and expedite new understandings and uses of plants and other organisms and microorganisms; (3) provide multidisciplinary training and research opportunities; and (4) apply innovation to meet future scientific, organizational and societal challenges and opportunities.

The CPBR brings together the resources of all its member organizations to address the problems and the future of U.S.-based businesses through a program of industrially relevant, scientifically meritorious, biotechnology-related plant research. The process of selecting research projects is highly competitive; it is a selection process which ensures that the research carried out through the CPBR has industrial interest, scientific merit, and high potential for the transfer of new technologies from the research laboratory to the marketplace.

CPBR Research Programs

Research Project Selection Process

The CPBR research project selection process is designed to ensure scientific excellence, provide for industrial involvement and maximize the potential for immediate transfer of research results to the industrial sector. To accomplish these goals, the CPBR conducts a two-stage review process: 1) an industrial preproposal review to assess the industrial relevance of proposed projects, and 2) a rigorous peer review of full proposals to assess scientific merit.

Energy from Biomass/Transportation Fuels Competition

The Energy from Biomass/Transportation Fuels competition encompasses applications of plant biotechnology to develop and improve alternative renewable energy sources, such as transportation fuels, and other products that can lessen U.S. reliance on petrochemicals and other non-renewable energy sources.

Energy from Biomass Projects

Current and previously funded projects address the needs of producing and converting biomass energy crops into energy resources for use in transportation fuels. Projects include increasing plant biomass by preserving the photosynthetic capacity of older leaves; developing novel propagation methods of aspen for use as energy crops; genetic engineering of insect resistance into poplar for use as a woody biofuels energy crop; genetic engineering of male-sterile clones to improve hybrid aspen for energy plantations; studies to asses the potential of willow species for biomass energy production; studies on biopulping to improve biomass conversion; development of transgenic aspen and alfalfa with reduced lignin content for easier conversion; conserving energy stocks by replacing petroleum/natural gas with biomass in the production of organic acids; converting corn residues and other agricultural residues into ethanol through the fermentation of waste sugars; converting waste paper products, lignocellulosics, into ethanol; and methods of converting carbon dioxide, the major byproduct of fermentation, to ethanol.

Electric Power from Biomass Competition

A new initiative, the Electric Power from Biomass Competition encompasses research on the production and conversion of biomass crops into electricity. Proposals in plant biotechnology research areas include basic biochemistry, physiology, genetic manipulation, cell/tissue culture techniques and bioengineering addressing industrial problems and opportunities related to electric power from biomass.

Today's Consortium

Through direct memberships and trade associations, nearly 200 U.S.-based corporations who operate in all fifty states participate in the CPBR. Several national labs are also involved. University membership has expanded to institutions across the nation, and today include leading research universities that have international reputations. These universities attract distinguished faculty, outstanding students and broad-based support from government, industry, and foundations. That support serves as an excellent springboard for companies initiating or expanding commercial biotechnology applications.

In an effort to foster and fund collaborations between international scientists and engineers in industry and academic research, the CPBR is currently seeking international partners through interested governmental agencies and other organizations. Through international collaboration, industry and university scientists from different countries can pool their resources and combine their different expertise to solve industrial problems on many continents.

CPBR Membership

Corporate Members

Amoco Corporation
Archer Daniels Midland Company
Biogenetic Services, Inc.
Biopulping Consortium II
Blandin Paper Company
Boise Cascade
Cargill, Inc.
Central and South West Services, Inc.
Central Golden Harvest Research
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The Dolet Hills Mining Venture
FMC Corporation
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University Members

Dartmouth College
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Iowa State University
Kansas State University
Louisiana State University
Michigan State University
Michigan Technological University
Montana State University
North Dakota State University
Northwestern University
The Ohio State University
Purdue University
South Dakota State University
Southern Illinois University
University of Chicago
University of Connecticut
University of Illinois
University of Iowa
University of Kentucky
University of Michigan
University of Minnesota

New Energy Company of Indiana
North American Coal Corporation
Northrup King Company
Pekin Energy Company
Phillips Coal Company
Pioneer Hi-Bred International, Inc.
The Procter & Gamble Company
The Quaker Oats Company
Red River Mining Company
Rhône-Poulenc

University of Missouri
University of Nebraska
University of Wisconsin
Washington University

Benefits to Industrial Members

U.S.-based companies interested in plant biotechnology research are invited to join the CPBR. Industry members enjoy multiple benefits, including:

Consortium Involvement:

Participate in setting CPBR's research agenda, which assures high industrial relevance of funded research; evaluate proposed research projects from concept through funding rankings; and appoint research liaisons to CPBR projects of interest.

In-Company Benefits:

Leverage corporate resources for R&D; enhance value-added job opportunities; improve education and training of future employees; and utilize regulatory adherence models.

Networking, Learning Opportunities:

Access new ideas and innovative thinking; establish valuable research contacts; network with university, industrial and federal laboratory scientists and engineers; and participate in research workshops and symposia.

Incorporating Research Results:

Review of early R&D results from top academic scientists and engineers; adopt product and process improvements developed through research; and tap commercial opportunities resulting from research.

Consortium Organization

Members of the CPBR are directly involved in governance of the organization through their election of a Board of Directors and a Secretariat. The Board of Directors is made up of an equal number of members from research institutions and companies, plus the president. The Board manages the business and affairs of the corporation and sets its budget. The Secretariat is a scientific advisory board with six members from research institutions and six members from companies and associations. The Secretariat makes project recommendations to the Board.

For More Information

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