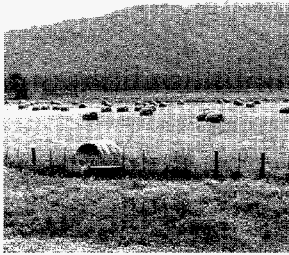


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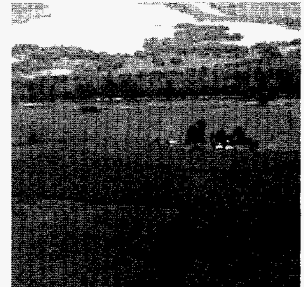
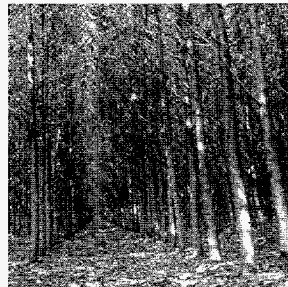
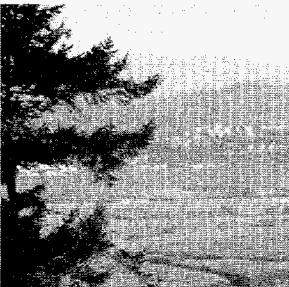
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Evaluation of
Herbaceous Biomass Crops
in the
Northern Great Plains



Final Report



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Evaluation of Herbaceous Biomass Crops in the Northern Great Plains

**Final Report
August 31, 1994**

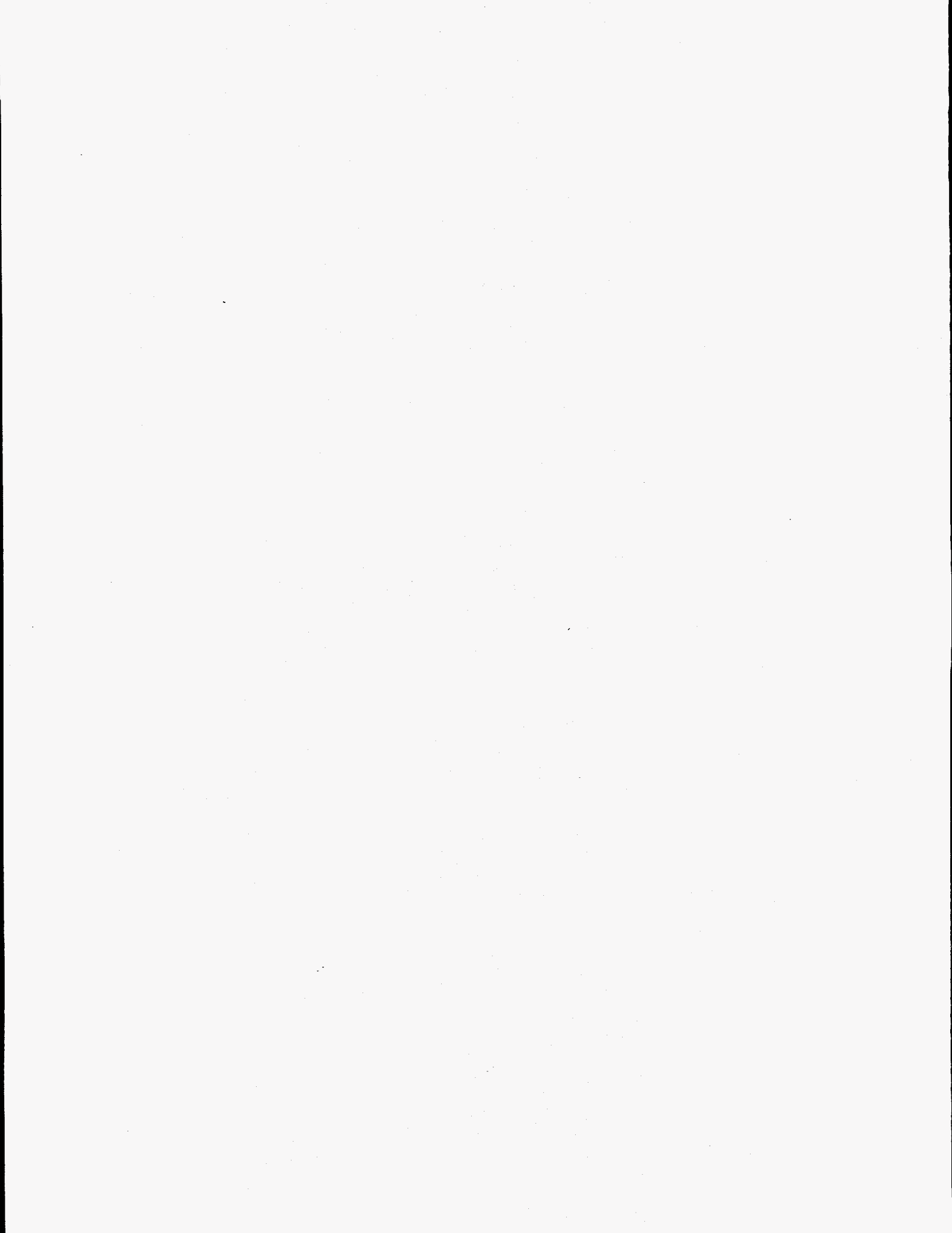
**D. W. Meyer
W. E. Norby
D. O. Erickson
R. G. Johnson**

**North Dakota Agricultural Experiment Station
North Dakota State University
Fargo, North Dakota**

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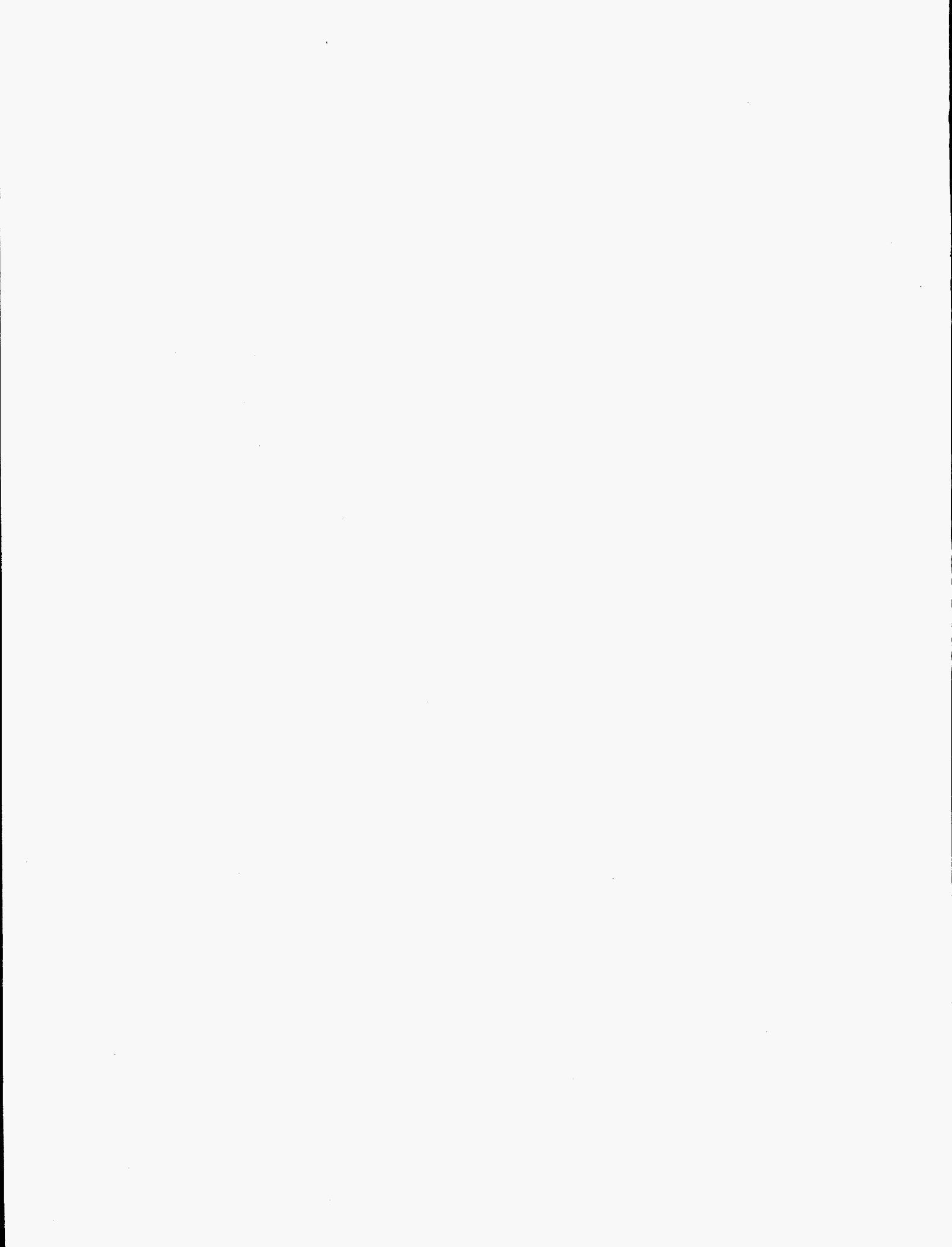


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EVALUATION OF HERBACEOUS BIOMASS CROPS IN THE NORTHERN GREAT PLAINS

Dwain W. Meyer, Wayne E. Norby, Duane O. Erickson, and Roger G. Johnson
North Dakota State University, SU Station, Box 5051, Fargo, ND 58105

Abstract

Herbaceous lignocellulose crops are a potential renewable feedstock for biochemical conversion systems second in size only to wood products. Several herbaceous crops are utilized as forage crops in the northern Great Plains, but forage quality considerations usually dictates a early harvest. Biomass cropping does not have this constraint; therefore, little information was available on herbaceous crops utilized as energy crops prior to this project. Our primary objectives were to evaluate the biomass yield and select chemical components of several herbaceous crops for energy crops in the northern Great Plains, compare the economic feasibility of energy crops with common competing crops, and evaluate biomass cropping on summer fallow lands.

Three good, two marginal, and one irrigated sites were used during 1988 to 1992 for the first component. At least six perennial and four annual biomass species were included at all sites. Three to four nitrogen (N) levels and a crop-recrop comparison (annuals only) were management intensities included. Biomass cropping on idled lands was performed on dryland at Carrington and evaluated the effects of removing leguminous biomass on fallowed lands. This report summarizes results from the 5-year project.

Forage sorghum produced the highest average biomass yield (16.9 Mg ha^{-1}) when meaned across years at the Carrington irrigated site, the highest average biomass yield at 4 of 6 sites, and the highest biomass yield (23.3 Mg ha^{-1}) in any one year and site. Sorghum X sudan and kochia were the highest yielding species each at one site, generally the droughty sites.

Perennial species generally did not have the biomass yield potential of the annuals. Switchgrass, where included, had the highest biomass yield (9.0 to 11.3 Mg ha^{-1} at two sites) of the perennials evaluated, intermediate wheatgrass and the CRP mixture generally were the highest yielding cool-season perennials.

Nitrogen fertilization levels above 50 kg ha^{-1} rarely increased biomass yields of annuals. Nitrogen fertilization was not needed for perennials the first two years, but was required the third and fourth years. Species by N level interaction was rarely significant. Growing biomass species on fallow probably does not pay even though slightly higher biomass yields occurred on fallow compared with recrop.

Although affected by species, the chemical composition of both annual and perennial species was affected more by the environment (site and year). Yield of chemical component was primarily affected by biomass yield and not chemical composition.

Herbaceous biomass cropping was an economically feasible alternative cropping enterprise in the three areas studied when biomass was valued at $\$39.2 \text{ Mg}^{-1}$. Kochia as a biomass crop was the most profitable species in all areas. If excluded, forage sorghum or sorghum X sudan was selected. Switchgrass was more profitable where included than the common small grains grown in the area.

Kochia, a common annual weed, has potential as a biomass crop in the northern Great Plains, but additional research on production and physiology factors is needed. For example, we have shown that harvest after a killing frost dramatically reduces biomass yields and allelopathic effects prevents economic yields when kochia is grown on land previously cropped to kochia. Likewise, additional research on stand establishment of switchgrass seems warranted.

Biomass cropping on idled/fallowed land was basically a failure due to poor establishment of the leguminous crop. We believe that the concept has merit, but establishment problems must first be solved.

We conclude from this 5-year study that herbaceous biomass cropping is economically feasible in the northern Great Plains. If herbaceous biomass has a place in the energy picture of the United States, the northern Great Plains should be considered as a potential major contributor.

INTRODUCTION

Herbaceous lignocellulosic crops are a potential renewable feedstock for biochemical or thermochemical conversion systems second in size only to wood products. If the long-term goal of the Department of Energy is to produce significant quantities of energy from renewable sources that is cost effective with other fuels, it is important that several herbaceous biomass crops and their management be evaluated in various regions of the United States.

Little information was available on the productive potential of herbaceous crops used for biomass production in the northern Great Plains prior to initiation of this project. What information available was obtained in evaluation of forage crops for livestock feed, but these data do not apply well to biomass production because forage quality, and not quantity, determines management practices.

Meyer (1979) evaluated sweet sorghum (*Sorghum bicolor* (L.) Moench) for its adaptation to the northern Great Plains. Maximum biomass yields of 17 genotypes evaluated was less than 15 Mg ha⁻¹ under irrigated conditions in an average year, but sugar accumulation in the stalks was very low compared with other regions. He concluded from this 1-year experiment that the environment at Fargo, ND, was too cool for consistent production.

Even less information was available on biomass production on marginal or idle (summer fallowed) cropland. The conservation reserve program (CRP) idled in excess of 1.3 million hectares in North Dakota alone. These CRP hectares represent a major land resource available for biomass production with herbaceous crops.

Idled cropland or fallow hectareage is the second block of land potentially utilizable for energy crop production. North Dakota alone has nearly 2.9 million hectares fallowed annually. Badaruddin and Meyer (1989) and Meyer (1987) have previously shown that a legume forage crop could be harvested in eastern North Dakota without substantially affecting subsequent crop productivity in average to above-average precipitation years. But, we need to determine the extent of fallow hectareage that could be tapped for leguminous biomass production and/or the effect of biomass cropping on subsequent crop productivity from not having fallow available for next year's crop production.

To be a viable alternative cropping enterprise, biomass cropping must compete economically with other cropping alternatives in the area. Land costs are relatively cheap and returns from competing cropping alternatives are relatively low in the northern Great Plains compared with other areas of the United States. Therefore, even though biomass yields may be lower than that produced in other areas, cost per unit of biomass may be cheaper.

OBJECTIVES

The primary goal of this project was to evaluate the potential of several herbaceous biomass crops in the northern Great Plains. Our specific 5-year objectives included:

1. Determine the biomass yield and select chemical composition of four annuals and at least six perennial herbaceous lignocellulosic crops at three good cropland sites, two marginal cropland sites, and one irrigated site in North Dakota.
2. Determine the effect of management intensities [nitrogen (N) level for all species and crop-fallow for annual crops] on biomass yield and chemical composition of four annual and at least six perennial crops across a precipitation gradient.
3. Determine the potential biomass yields on normal fallowed land and its effect on subsequent crop yields.
4. Evaluate the economic feasibility of the various herbaceous energy crops compared with competing crops in the northern Great Plains.

MATERIALS AND METHODS

Objectives 1 and 2

Detailed description of materials and methods used in this series of field experiments conducted to meet the objectives are presented elsewhere by Meyer et al. (1989-93). A brief overview of the project follows.

Field experiments were conducted at six North Dakota sites during 1988 to 1992. Five dryland sites and one irrigated site representative of the three major soil areas or regions of North Dakota were chosen (Figure 1). Site 1 is located in the Red River Valley of the North at Prosper, ND, on a productive Gardena silt loam soil (coarse-silty, mixed, Pachic Udic Haploboroll) about 40 km northwest of Fargo, ND. Site 2 is located on the Hettinger Research and Extension Center at Hettinger, ND, on a productive Shambo silt loam soil (fine-loamy, mixed, Typic Haploboroll), and is representative of farmland south and west of the Missouri River in an unglaciated region of the Missouri Plateau. Site 3 (Glenfield Good) is located near Glenfield, ND, on a productive Barnes loam gradating to a Svea loam soils (fine-loamy, mixed, Udic Haploborolls) with numerous rocks typical of the Drift Prairie of east-central North Dakota.

Sites 4 and 5 are marginal cropland locations that qualify as CRP hectarage. Site 4 is located at Leonard, ND, on a fairly productive, Hecla loamy fine sand (sandy, mixed, Aquic Haploboroll), which is highly susceptible to wind erosion. This site is located about 48 km southwest of Fargo (Figure 1). Site 5 (Glenfield Poor) is located near Glenfield, ND, on the crest of hills, which is typical of the poor soil types in the Drift Prairie. The soil is a Buse loam (fine-loamy, mixed, Udorthentic Haploboroll). Site 6 (Carrington irrigated) is located at the Carrington Research and Extension Center at Carrington, ND, and is an irrigated site in the Drift Prairie. Detailed description and the physical and chemical makeup of the soils at each site were presented by Meyer et al. (1991). Soil loss estimated by the universal soil-loss equation for each site was reported by Meyer et al. (1992).

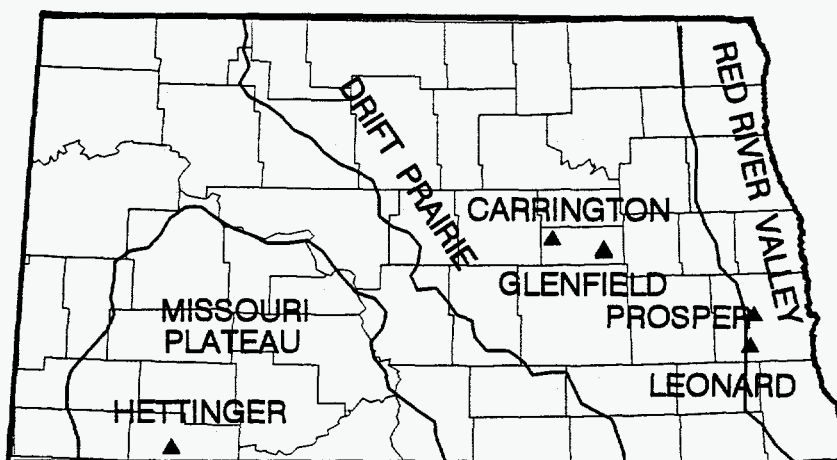


Figure 1. Location of sites used in the North Dakota biomass experiments.

These six sites normally have a precipitation gradient with Carrington the greatest (irrigated), Prosper and Leonard intermediate, Glenfield next, and Hettinger least. Normal precipitation for the growing season at each site is presented in Table 1.

Ten perennial species/mixtures were evaluated including four cool-season grasses ('Palaton' reed canarygrass, *Phalaris arundinacea* L.; common brome grass, *Bromus inermis* Leyss.; 'Nordan' crested wheatgrass, *Agropyron desertorum* (Fisch. ex Link) Schult.; and 'Ohae' intermediate wheatgrass, *Thinopyrum intermedium* (Host) Barkw. & D.R. Dewey), two warm-season grasses ('Sunburst' switchgrass, *Panicum virgatum* L. and SD 43 big bluestem, *Andropogon gerardii* Vitman var. *gerardii*), and four mixtures (brome-alfalfa, *Medicago sativa* L.; intermediate-western wheatgrasses, *Pascopyrum smithii* (Rydb.) A. Löve; switchgrass-brome; and a CRP mixture [intermediate wheatgrass, tall wheatgrass (*Thinopyrum ponticum* (Podp.) Barkw. & D.R. Dewey), alfalfa, and sweetclover (*Melilotus officinalis* Lam.)]. The last mixture was chosen since this "wildlife mixture" is a common mixture used on CRP hectareage.

All cool-season perennial plots were seeded at 323 seeds m^{-2} , except reed canarygrass which was doubled, following careful seedbed preparation during the last week of April and first week of May 1988. Warm-season species were seeded the third week of May, typical recommended dates for these species. A specially design drill by researchers at the Northern Great Plains Research Center at Mandan, ND, was used to seed all plots. Unique characteristics of this seeder includes a series of packer wheels replacing the normal drive wheels of the power unit, which firms the seedbed and permits precise, shallow seeding; depth bands set at 2-cm seeding depth on the double-disc openers; cone seeder with rotating spreader; and rear packer wheels. This drill normally gives excellent stands of small-seeded species/mixtures in the semi-arid environment of the northern Great Plains. The seeder plants 10 rows on 15-cm centers. An experimental unit was 7.6 m in length by 1.5 m in width.

All perennials were seeded during late April and early May, but marginal stands occurred at all sites due to the near record drought of 1988; therefore, cool-season species/mixtures at all sites were reseeded or renovated (Glenfield Poor) during 15 to 22 August using similar techniques to the spring seedings. Warm-season species were seeded the following spring. The new seedings at Prosper,

Table 1. Growing-season precipitation at five North Dakota sites in 1988 to 1992.

Month	Normal	Departure from normal				
		1988	1989	1990	1991	1992
-----mm-----						
<u>Prosper†</u>						
April	48	-25	-20	0	11	-40
May	57	-20	6	-12	32	- 3
June	78	-44	-28	89	34	106
July	85	-69	-65	-69	4	23
August	66	-14	71	15	-17	50
September	48	29	- 9	- 4	- 6	18
Total	381	-143	-45	19	58	153
<u>Hettinger</u>						
April	42	-42	92	-24	- 4	
May	69	- 5	-48	-39	1	
June	91	-33	-58	-18	39	
July	50	-12	-12	-24	-13	
August	44	-27	48	-26	-25	
September	36	-10	- 7	-34	-20	
Total	332	-129	15	-165	-22	
<u>Leonard‡</u>						
April	49	-45	-12	- 9	30	- 5
May	68	-11	-24	32	53	1
June	95	-57	-42	48	51	31
July	69	-29	-18	-44	-25	1
August	64	- 3	5	32	-28	- 1
September	46	33	-13	14	14	- 5
Total	392	-112	-104	73	95	22
<u>Glenfield§</u>						
April	32		-19	- 1	5	-21
May	55		0	-31	1	-16
June	86		-29	119	-15	-35
July	63		-15	-20	16	-23
August	61		86	- 8	-14	-14
September	45		-31	5	50	- 8
Total	344		- 8	64	43	-118
<u>Carrington irrigated¶</u>						
April	40	-30	-27	0	13	-27
May	63	-48	9	-28	13	-33
June	94	-63	-43	150	22	-61
July	63	-52	-22	-12	9	-25
August	53	-21	89	-15	-31	13
September	43	-29	45	12	26	7
Total	356	-243	51	107	52	-126

† Prosper data is from Agronomy Seed Farm with departure from normal derived from Fargo data.

‡ Leonard data is from regional average for southeast ND.

§ Glenfield data is from McHenry NDAA weather station approximately 8 miles from the Glenfield site.

¶ Carrington departure from normal is taken from Carrington NDAA data at Carrington airport and applied to Carrington Res./Ext. Center data.

Leonard, and two Glenfield sites were watered (approximately 0.8 cm per application) once or twice a week starting 1 week after planting until the first week of October to aid germination and establishment. The sites were watered as frequently as possible with a 1512-L tank on the back of a pickup truck. Fortunately, adequate rainfall and cooler temperatures in September allowed establishment of good stands at these sites.

The number of plants m^{-2} and average growth stage were determined for each of the seven species/mixtures in two replicates at Prosper and Leonard sites in October 1988. In general, the majority of species/mixtures had stand densities of 215 to 323 plants m^{-2} and was in the 2 to 4-leaf stage. Meyer and Rugroden (1988) reported that as little as 11 uniformly distributed plants m^{-2} produced fully productive stands by the second harvest year. Observations at Glenfield and Carrington indicated similar progress, but plants were in the 1 to 2-leaf stage. Plants at the Hettinger site did not emerge due to lack of precipitation.

Stand evaluations in spring 1989 indicated good to excellent grass stands at Carrington, Prosper, Leonard, and Glenfield Good and Poor sites, but the legume component was very poor. Therefore, a broadcast seeding of the legumes was performed at each site but with little success. Warm-season species were reseeded at all sites and the cool-season species/mixtures at Hettinger in 1989. Unfortunately, warm-season grass establishment was poor at most sites except Prosper and, to a lesser degree, Leonard. Cool-season species/mixtures at Hettinger established only marginal stands.

All established perennial cool-season species/mixtures were fertilized with N (urea, 46-0-0) at 0, 50, and 100 $kg\ ha^{-1}$ beginning spring 1989. An additional N level of 200 $kg\ ha^{-1}$ was used at Carrington and Prosper. Subsequent year's fertilization occurred in late October. All warm-season perennial plots considered established were fertilized with N at the same rates in mid May to help reduce cool-season grass encroachment.

The field design for the perennial experiments was a randomized complete block in a split-plot arrangement. The mainplots were species and the subplots were N levels. Three replicates were used at all sites.

Cool-season grasses/mixtures were harvested with a flail mower in July each year and warm-season grasses in August. The harvested area was 0.86 by 6.12 m or 5.26 m^2 . Biomass of each plot was weighed to determine field weight, sampled for moisture, and the sample dried in a force-air oven at 50°C. The samples were ground to pass a 1-mm screen in a Wiley mill, mixed thoroughly, subsampled, and stored in sealed plastic or glass containers until chemical analyses were performed. All remaining biomass in the field after harvest was removed. Regrowth usually was minimal and left standing in the field. A second harvest was taken at Leonard in 1990.

Annual herbaceous species used at the six sites were 'Pioneer 3974' corn, *Zea mays* L., for grain; DeKalb variety FS25E forage sorghum, *Sorghum bicolor* (L.) Moench; DeKalb variety ST6E sorghum X sudangrass cross (sorghum X sudan); 'German' foxtail millet, *Setaria italica* (L.) P. Beauv.; common sweetclover, and common kochia, *Kochia scoparia* L. Sweetclover and kochia were planned to be volunteering species. Corn was included as an environmental check and was over seeded and thinned to 69,000 plants ha^{-1} at Carrington and 44,500 plants ha^{-1} at other sites. The sorghums were seeded at 28 $kg\ ha^{-1}$, foxtail millet at 22 $kg\ ha^{-1}$, sweetclover at 10 $kg\ ha^{-1}$, and kochia at about 5 $kg\ ha^{-1}$. An experimental unit consisted of four rows spaced 61 cm apart for corn and sorghums, eight 30-cm rows for foxtail millet, and broadcast stands for kochia. All plots were 6.12 m in length.

Management intensities included were crop-recrop initiated in 1989 and N levels. Hard red spring wheat (*Triticum aestivum* L. emend. Thell.) usually was the recrop species. The sorghums and foxtail millet were fertilized with urea at 50, 100, and 200 $kg\ N\ ha^{-1}$. It became apparent in 1989 that the volunteering kochia and sweetclover treatments would not work so they were discontinued and only an annually seeded kochia treatment fertilized at 50 $kg\ N\ ha^{-1}$ was included instead. Kochia and sweetclover were unfertilized in 1988.

The field design for annual experiments was a randomized complete block with a split-split-plot arrangement. Crop-recrop was the mainplot, species the subplot, and N level the sub-subplot. A split-plot analysis was used when the crop-recrop comparison was not included.

The annuals were seeded in well-prepared seedbeds usually during mid May. Nitrogen fertility treatments were applied immediately following planting. Weed control was via herbicides and hand-weeding where deemed necessary. Corn and sorghum treatments at all sites were sprayed postemergence with atrazine, 6-chloro-*N*-ethyl-*N'*-(1-methylethyl)-1,3,5-triazine-2,4-diamine, at 1.12 kg ha⁻¹ and crop oil (3.78 L ha⁻¹). Foxtail millet plots were wheel-hoed twice since millet is injured easily by atrazine. Kochia treatments had no weed control practices applied.

Biomass yields of row-crop annuals were determined by hand harvesting during September. Foxtail millet and kochia were harvested with a Jari mower about 2 weeks before a killing frost to prevent seed drop. A middle row of corn and sorghum, two middle rows of foxtail millet, and an area of kochia 86-cm wide by 4.5 m in length constituted the harvest plot. All samples from each treatment were handled similar to perennial samples.

Select chemical composition was determined on all samples from two replicates of all perennial and annual biomass species and for all management-intensity treatments. Acid-detergent fiber (ADF), neutral-detergent fiber (NDF), and acid-detergent lignin (ADL) concentrations were determined by the methods of Goering and Van Soest (1970). Hemicellulose was calculated as NDF-ADF and cellulose as ADF-ADL. Nitrogen, ash, and dry matter concentrations were determined by AOAC methods. Total nonstructural carbohydrate (TNC) concentration was determined using procedures of Smith (1980). Biomass yields are reported on the dry matter basis. Yields of chemical components were determined by multiplying the biomass yield by the appropriate chemical constituent. Average concentration of the two replicates determined was used to calculate yields in the third replicate.

Analyses of variance using the SAS system were determined on biomass yields, chemical component concentrations, and chemical component yields. Appropriate analyses for a randomized complete-block design with treatments in a split (perennials) or split-split-plot (annuals) arrangements were used. Species, N levels, and cropping treatments were considered fixed effects. Years and sites were considered random effects. Where significant F-tests were detected, least significant differences (LSD) were used to separate means. Two separate analyses were determined on the annuals due to the unbalanced nature of the treatments. First, species significance was determined by deleting all fertility treatments above 50 kg N ha⁻¹ from the data set. Second, kochia treatments were deleted, and the cropping system, fertility level, and two- and three-way interactions determined. Reported significance for these effects was based on these analyses.

Biomass cropping across a precipitation gradient was evaluated by plotting biomass yields (meaned across N levels) for each perennial and recrop annual species at each site and year versus growing-season precipitation. Linear regression equations were calculated and goodness of fit evaluated by the coefficient of determination (r^2).

Objective 3

'Nitro' alfalfa and common sweetclover were seeded without a companion crop on recrop land at Carrington, ND, in 1990. Trifluralin, 2,6-dinitro-*N,N*-dipropyl-4-(trifluoromethyl)benzenamine, at 0.7 kg ha⁻¹ was preplant incorporated for weed control. In addition, a 'Stoa' spring wheat treatment fertilized with 100 kg N ha⁻¹ and a fallow treatment were included as common farming practices of the area. Plots were arranged in the field in a randomized complete-block design, and three replicates were used. Similar experiments were seeded in 1988 and 1989, but inadequate stands occurred due to the extreme droughty conditions (Table 1) and the experiments abandoned.

Biomass harvests were taken 15 Aug. 1990 on 1-cut alfalfa and sweetclover plots and again 12 October on 2-cut alfalfa plots by harvesting an area of at least 7 m². Samples for dry matter determination were dried at 50°C. Following the second harvest, half the plots were rototilled to incorporate all remaining vegetation while the remaining plots left the vegetation stand over the winter attempting to trap snow to replace some of the soil moisture utilized by the biomass crop.

In 1991, Stoa wheat and 'Hazen' barley (*Hordeum vulgare* L.) were seeded at 80 and 60 kg ha⁻¹, respectively, across all 1990 treatments following a field cultivator seedbed preparation. The field design was a randomized complete block with treatments in a split-plot arrangement. Cropping

treatment in 1990 was the mainplots, wheat or barley the subplot, and N level the sub-subplot. Nitrogen at 0, 75, and 150 kg ha⁻¹ was applied as urea immediately following seeding. Weeds were controlled with a 1.12 kg ha⁻¹ application of diclofop, (±)-2-[4-(2,4-dichlorophenoxy)phenoxy] propanoic acid, and 2,4-D. Grain was harvested in early August with a Hege combine. Harvest plot was 1.2 by 6 m. All wheat and barley grain samples were cleaned, dried, and grain yield expressed on 140 or 120 g kg⁻¹ moisture concentration, respectively.

RESULTS AND DISCUSSION

Precipitation

Growing-season precipitation as departure from the long-term average is presented in Table 1. Precipitation ranged from 112 to 243 mm below the long-term average during 1988, which made it nearly impossible to establish small-seeded perennials even with light supplemental irrigation.

Growing-season precipitation at Prosper increased each year of the experiment with 1989 below normal, 1990 near normal, and 1991-92 above normal (Table 1). Distribution was poor during most years. Normal and above-normal years were associated with excessive precipitation during late May and June.

Hettinger was the most droughty environment as expected (Table 1), but 2 of 4 years were very dry even by its standard. Leonard was much below normal in 1988 and 1989, above normal in 1990 and 1991, and near normal in 1992. Glenfield was extremely dry in 1992, near normal in 1991 and 1989 due to late-season precipitation, and above normal in 1990 due to excessive precipitation in June. Carrington was very dry in 1992, and above normal during 1989-91. Distribution however was extremely erratic in 1989 and 1990.

Perennial Biomass Yields

Biomass yields meaned across years and N levels of several perennial species/mixtures at six North Dakota sites is presented in Figure 2. The greatest average biomass yield (8.66 Mg ha⁻¹) was produced at the Leonard site primarily due to the exceptionally high yields produced with two cuts in 1990 (Table 2). This was somewhat surprising since the site was chosen as a marginal site due to its extreme vulnerability to wind erosion. Carrington irrigated and Prosper followed closely behind Leonard (Figure 2). Biomass yields at Carrington were disappointing for an irrigated site. Stands were excellent, but irrigation may not have been as timely as needed for maximum yield. Perennials at Glenfield Good averaged 3.75 Mg ha⁻¹, 0.92 Mg ha⁻¹ greater than the Poor site. Hettinger, as expected, had the lowest average biomass yields of the six sites due to the poor environmental conditions (Table 1) and poorest stands of all sites.

Nitrogen fertilization treatment had little effect on biomass yields during 1989 and 1990, but had significant effects at most sites in 1991 and 1992 (Table 3). Applications of 50 kg N ha⁻¹ produced near maximum yields at Hettinger in 1991 and Glenfield Good and Poor in 1991 and 1992, 100 kg N ha⁻¹ was required at Leonard and Carrington irrigated in 1991 and Prosper in 1992, and 200 kg N ha⁻¹ at Leonard and Carrington in 1992. Apparently, some N is being lost with the flood irrigation at Carrington since biomass yields at 200 kg N ha⁻¹ were less than 100 kg N ha⁻¹ at Prosper and Leonard. These results follow closely the present recommendation by North Dakota State University to apply 45 kg N ha⁻¹ to established cool-season grasses in low rainfall areas and 80 to 110 kg N ha⁻¹ in higher rainfall areas.

Response to N fertilization was similar among species/mixtures as indicated by the lack of a species X N level interaction at most sites in 1991 and 1992 (Table 3). A lack of a N response to N fertilization for switchgrass was the primary cause of the significant interaction in 1992 at Prosper and may be associated with 1992 being the first year a N fertilization response was detected. Alternatively, switchgrass is a warm-season grass which may have a different N-use pattern than the cool-season grasses used at the other sites. However, biomass yields averaged over N level and years are reduced in 1991 and 1992 by including the nonfertilized treatment; therefore, reported biomass yields for the

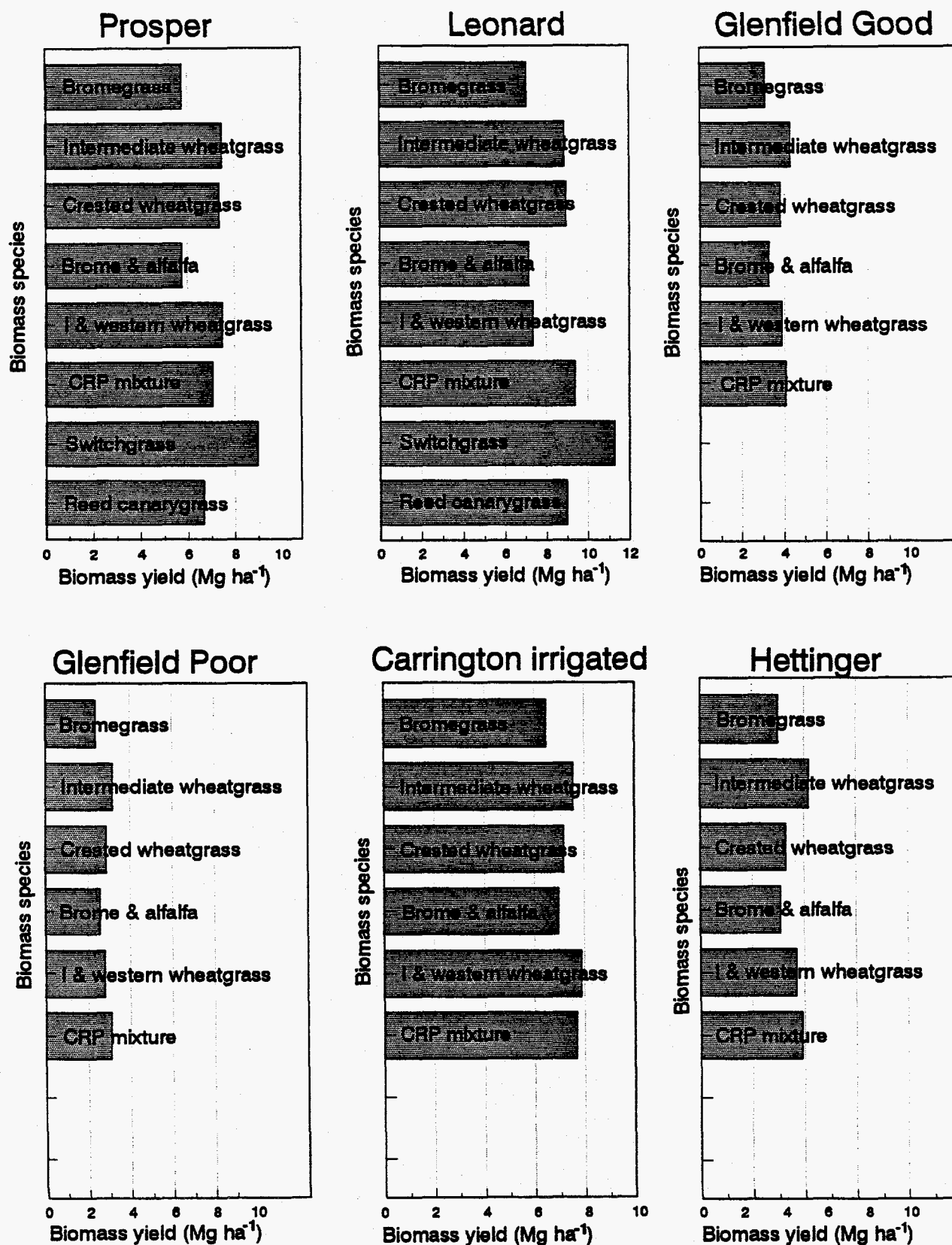


Figure 2. Biomass yields of several perennial species/mixtures at six North Dakota sites (meaned across years and N levels).

Table 2. Biomass yield of several perennial species meaned across 3 or 4 N levels at six North Dakota sites in 1989-92.

Species	Sites [†]					
	1	2	3	4	5	6
-----Mg ha ⁻¹ -----						
<u>1989</u>						
Bromegrass	6.6	--	1.6	--	0.7	8.3
Intermediate wheatgrass (I)	10.2	4.6	2.1	9.6	1.1	9.6
Crested wheatgrass	9.1	4.1	2.2	9.0	1.6	8.1
Brome-alfalfa	6.7	--	1.9	7.4	1.3	8.8
I & western wheatgrass	9.7	3.9	2.0	8.2	0.9	9.8
CRP mixture [‡]	8.7	4.8	2.1	10.5	1.1	8.8
LSD (0.05)	1.7	--	NS	NS	NS	NS
CV (%)	14.0	--	23.2	12.8	13.3	12.8
<u>1990</u>						
Bromegrass	6.2	2.0	5.5	9.6	4.7	8.2
Intermediate wheatgrass	7.3	3.5	7.1	14.4	5.6	9.9
Crested wheatgrass	7.7	2.7	6.5	15.0	5.0	9.5
Reed canarygrass	8.0	--	--	6.6	--	--
Brome-alfalfa	6.3	2.1	5.8	11.7	4.9	9.4
I & western wheatgrass	7.3	2.7	6.9	11.9	5.3	10.4
CRP mixture [‡]	7.0	2.7	6.9	14.5	5.7	10.0
Switchgrass	7.3	--	--	12.5	--	--
Big bluestem [§]	4.4	--	--	--	--	--
LSD (0.05)	1.6	1.1	1.0	2.8	NS	NS
CV (%)	26.2	38.4	14.1	33.8	37.1	18.8
<u>1991</u>						
Bromegrass	5.8	4.0	2.5	5.6	2.3	5.5
Intermediate wheatgrass	6.7	4.9	3.4	5.2	3.1	6.6
Crested wheatgrass	7.3	3.9	3.5	6.3	3.3	5.0
Reed canarygrass	5.7	--	--	8.5	3.4	4.9
Brome-alfalfa	5.1	4.1	2.7	5.2	2.5	5.1
I & western wheatgrass	7.1	4.7	3.3	5.0	2.9	6.6
CRP mixture [‡]	6.6	5.1	3.3	6.4	2.9	6.1
Switchgrass	9.3	--	--	8.6	3.5	--
Big bluestem [§]	5.9	--	--	5.7	--	--
LSD (0.05)	1.0	1.1	0.7	3.8	0.9	0.7
CV (%)	4.8	13.3	20.7	48.8	28.5	13.8
<u>1992</u>						
Bromegrass	4.8		2.9	5.7	1.9	4.0
Intermediate wheatgrass	5.8		4.6	6.3	3.0	5.8
Crested wheatgrass	5.5		3.0	5.9	1.9	4.6
Reed canarygrass	6.3		--	11.9	--	4.3
Brome-alfalfa	5.2		3.0	4.7	1.8	4.9
I & western wheatgrass	5.8		3.6	4.7	2.1	5.0
CRP mixture [‡]	6.1		4.1	6.1	2.7	5.9
Switchgrass	10.3		--	12.8	--	--
LSD (0.05)	1.1		0.7	1.9	0.6	0.7
CV (%)	19.6		17.5	24.4	35.4	15.6

[†] Sites are: 1 = Prosper, 2 = Hettinger, not harvested in 1992, 3 = Glenfield Good, 4 = Leonard (marginal), 5 = Glenfield Poor (marginal), and 6 = Carrington (irrigated).

[‡] Intermediate wheatgrass, tall wheatgrass, alfalfa, and sweetclover mixture.

[§] A single rep harvested.

Table 3. Nitrogen level effects on average perennial biomass yields at six North Dakota sites during 1991-1992.

Nitrogen level	Site [†]					
	1	2	3	4	5	6
kg ha ⁻¹	Mg ha ⁻¹					
	<u>1991</u>					
0	6.7	3.8	2.5	5.9	2.5	4.9
50	6.8	4.6	3.3	6.3	3.1	5.8
100	6.9	4.7	3.5	7.1	3.1	6.3
200	6.4					6.5
Mean	6.7	4.3	3.1	6.4	2.9	5.9
LSD (0.05)	NS	0.4	0.3	0.7	0.2	0.6
Species X N level	NS	NS	NS	NS	NS	**
	<u>1992</u>					
0	4.8		2.3	5.9	1.6	3.8
50	6.3		4.1	7.4	2.6	4.9
100	6.9		4.2	8.4	2.6	5.3
200	6.9					6.2
Mean	6.2		3.5	7.3	2.2	5.1
LSD (0.05)	0.7		0.3	0.9	0.2	0.8
Species X N level	**		NS	NS	NS	NS

** Significant at $P < 0.01$.

[†] Sites are: 1 = Prosper, 2 = Hettinger not harvested in 1992, 3 = Glenfield Good, 4 = Leonard (marginal), 5 = Glenfield Poor (marginal), and 6 = Carrington (irrigated).

species/mixtures are conservative and would increase if the optimum fertilization was used to calculate species and site effects.

Switchgrass, where adequate stands developed, produced the greatest biomass yields of species tested (Figure 2, Table 2). Switchgrass averaged 11.3 Mg ha⁻¹ at Leonard and 9.0 Mg ha⁻¹ at Prosper during 1990-92. The single-plot observation at Glenfield Poor site in 1991 indicated that switchgrass was competitive in biomass yields with the other species. The major disadvantage of switchgrass was the poor establishment compared with the cool-season species/mixtures. Early observations indicated that switchgrass usually emerged, but plants did not establish. When it became obvious that we had establishment problems with switchgrass, a late summer seeding of switchgrass was seeded to initiate an add-on experiment. However, the 20 to 25-cm-tall, 2 to 3-leaf switchgrass plants did not overwinter. It is clear that additional work on switchgrass establishment is warranted.

Bromegrass and brome-alfalfa mixture generally were the lowest yielding biomass species/mixture at all sites (Figure 2, Table 2). Little alfalfa established in the brome-alfalfa treatment due to the fall seeding so it is no surprise that the biomass yields of these treatments were very similar at most sites. Intermediate wheatgrass, intermediate-western wheatgrasses, and the CRP mixture

generally were similar in biomass yields across sites, the intermediate-western mixture at Leonard a possible exception (Figure 2). Again, the CRP mixture had little legume component and was dominated by intermediate wheatgrass. Crested wheatgrass was included as a drought-tolerant species and was expected to perform well in the droughty environments, but there was little evidence to support this.

Biomass yields of brome grass at Prosper during the four years of this experiment (Table 2) have been very similar to well-fertilized forage yields of brome grass harvested at anthesis growth stage at Fargo over the past 35 years (Meyer et al., 1992). This suggests that the Prosper data should be near that expected over many years.

Chemical Composition of Perennial Species

Chemical composition of perennial biomass species as influenced by environments is presented in Table 4. Many chemical components had a significant year X site interaction indicating that the chemical composition can be expected to vary with site and production year. The significant interaction was caused by changes in relative ranking of a component among years. For example, the ash concentration was highest at Glenfield Good in 1989, 1991, and 1992, but lowest in 1990. The data suggest that it is impossible to accurately predict the chemical composition of a perennial biomass species at a particular site and year by other than a "ballpark" figure.

Nitrogen fertilization had little effect on the chemical composition of perennial biomass species in the first year of production (Table 5), and had several significant effects at only Glenfield Good and Carrington irrigated in 1990. Significant differences by N level were detected in about half of the comparisons of chemical components within sites in 1991 and 1992, but a consistent trend for N level effects across sites was evident only for N concentration (data not shown). Where significant N effects were detected, ash, ADF, TNC, and cellulose concentrations generally decreased with increasing N level and NDF, ADL, N, and hemicellulose increased. Even where significant differences in chemical composition occurred, relative differences were small for all but N concentration, indicating that N fertilization has its greatest effect on biomass yield and only minor effects on the chemical composition. Nitrogen effects within 1991 and 1992 were discussed by Meyer et al. (1993).

Cool-season grass species/mixtures at Prosper generally differed little in chemical composition when meaned across years and N levels, the "ballpark" estimate (Table 6, Fig. 3). This is not too surprising when the makeup of field plots was evaluated. The three cool-season mixtures generally had few legume components and/or were dominated by intermediate wheatgrass. This caused brome grass and brome-alfalfa, and intermediate wheatgrass, intermediate/western wheatgrasses, and the CRP mixture to be quite similar in chemical composition and act more like two treatments than five. Still, reed canarygrass, brome grass, and brome-alfalfa generally had higher ash and N concentrations than the other species/mixtures, but NDF, ADF, hemicellulose, and cellulose concentrations were very similar. Crested wheatgrass had a higher TNC and a lower ash content than most other cool-season species/mixtures. Brome grass and brome-alfalfa were slightly higher in ADL.

Switchgrass and big bluestem [only isolated comparisons, Meyer et al. (1993)], warm-season species, had significantly greater NDF and hemicellulose and less ash, N, and ADL concentrations than most cool-season species/mixtures (Fig. 3, Table 6). These species were the major cause of significant species differences in chemical composition where included in the treatments (especially at Prosper). These differences were expected and follow known differences between warm- and cool-season grasses.

Table 4. Chemical composition of perennial biomass species as influenced by site and year (meaned across species and N levels).

Site	Chemical component [†]							
	Ash	NDF	ADF	ADL	N	TNC	HEMI	CELL
-----g kg ⁻¹ dry weight-----								
<u>1989</u>								
Prosper	90	698	438	62	17.0	58	260	374
Glenfield Good	156	613	375	53	22.0	52	238	322
Leonard	115	684	453	57	17.0	93	231	395
Glenfield Poor	144	627	363	45	21.0	68	264	318
Carrington (irrigated)	89	638	437	68	10.0	--	201	374
<u>1990</u>								
Prosper	108	683	455	63	17.0	73	228	392
Hettinger	110	659	399	48	18.0	69	260	351
Glenfield Good	81	667	430	51	11.0	107	237	379
Leonard H1 [‡]	109	685	449	58	16.0	88	236	391
Leonard H2 [‡]	111	653	341	37	23.0	--	312	304
Glenfield Poor	80	658	419	50	12.0	67	239	369
Carrington (irrigated)	84	639	434	55	13.0	111	205	379
<u>1991</u>								
Prosper	100	662	412	56	15.0	75	250	356
Hettinger	108	649	381	48	18.1	82	268	333
Glenfield Good	144	658	403	48	13.0	93	255	354
Leonard	84	686	440	57	10.6	82	246	384
Glenfield Poor	109	664	402	49	12.7	79	262	353
Carrington (irrigated)	95	641	433	53	9.4	92	208	380
<u>1992</u>								
Prosper	90	629	389	43	16.2	71	240	346
Glenfield Good	115	618	384	40	14.9	50	234	343
Leonard	90	658	409	44	11.4	72	250	365
Glenfield Poor	103	615	385	39	15.0	66	231	346
Carrington (irrigated)	98	607	380	40	11.3	90	219	348

[†] NDF = neutral-detergent fiber, ADF = acid-detergent fiber, ADL = acid-detergent lignin, N = nitrogen, TNC = total nonstructural carbohydrates, HEMI = hemicellulose (NDF-ADF), and CELL = cellulose (ADF-ADL).

[‡] H1 = Harvest 1, H2 = Harvest 2.

Table 5. Significance of nitrogen effect on chemical composition of perennial biomass species at six North Dakota sites in 1989-92 (meaned across species).

Site	Chemical component [†]							
	Ash	NDF	ADF	ADL	N	TNC	HEMI	CELL
<u>1989</u>								
Prosper	*	NS	NS	NS	NS	NS	NS	NS
Glenfield Good	NS	NS	NS	NS	NS	NS	NS	NS
Leonard	NS	NS	NS	NS	NS	NS	NS	NS
Glenfield Poor	NS	NS	NS	NS	NS	*	NS	NS
Carrington irrigated	NS	NS	NS	NS	NS	--	NS	NS
<u>1990</u>								
Prosper	NS	NS	NS	NS	NS	NS	NS	NS
Hettinger	NS	NS	NS	NS	NS	NS	NS	NS
Glenfield Good	NS	*	NS	*	*	*	*	*
Leonard	NS	NS	NS	NS	NS	*	NS	NS
Glenfield Poor	NS	NS	NS	NS	*	NS	NS	*
Carrington irrigated	NS	NS	*	*	*	NS	NS	*
<u>1991</u>								
Prosper	NS	NS	NS	*	*	*	NS	*
Hettinger	NS	*	*	*	*	NS	NS	*
Glenfield Good	*	NS	*	NS	*	NS	*	*
Leonard	NS	NS	NS	NS	NS	NS	NS	NS
Glenfield Poor	*	NS	*	NS	*	*	*	*
Carrington irrigated	*	*	NS	NS	*	NS	NS	NS
<u>1992</u>								
Prosper	NS	NS	*	*	*	NS	NS	*
Glenfield Good	*	NS	*	NS	*	NS	*	*
Leonard	NS	NS	NS	*	*	NS	NS	NS
Glenfield Poor	*	NS	NS	NS	*	NS	NS	NS
Carrington irrigated	*	*	NS	NS	*	NS	*	NS

* Significant at $P < 0.05$.

[†] NDF = neutral-detergent fiber, ADF = acid-detergent fiber, ADL = acid-detergent lignin, N = nitrogen, TNC = total nonstructural carbohydrates, HEMI = hemicellulose (NDF-ADF), and CELL = cellulose (ADF-ADL).

Cool-season grass species/mixtures at sites other than Prosper also differed little in chemical composition when meaned across years and N levels (Table 6). Crested wheatgrass generally was the lowest species/mixtures in ash, cellulose, and ADF concentrations across sites. Bromegrass and brome-alfalfa generally were highest of the cool-season species/mixtures in ash and N concentrations.

Table 6. Chemical composition of several perennial biomass species at six North Dakota sites (meaned across years and 3 or 4 N levels).

Species	Chemical component [†]							
	Ash	NDF	ADF	ADL	N	TNC	HEMI	CELL
-----g kg ⁻¹ dry weight-----								
<u>Prosper (Site 1)</u>								
Bromegrass	100	659	423	60	16.7	63	236	363
Intermediate wheatgrass (I)	92	665	426	53	12.7	69	239	373
Crested wheatgrass	80	654	405	60	16.1	81	250	345
I & western wheatgrass	98	671	429	52	15.4	62	242	377
CRP mixture	92	665	427	53	15.6	69	238	374
Brome-alfalfa	105	655	420	64	19.2	59	235	357
Switchgrass [‡]	70	723	413	47	10.0	82	310	366
Reed canarygrass [‡]	130	662	416	51	20.0	67	246	365
<u>Hettinger (Site 2)</u>								
Bromegrass	121	660	399	47	20.4	54	261	352
Intermediate wheatgrass	86	663	385	51	16.1	98	278	334
Crested wheatgrass	126	632	386	49	21.9	61	246	337
Brome-alfalfa	103	650	388	46	17.1	79	262	341
<u>Glenfield Good (Site 3)</u>								
Bromegrass	131	643	402	48	17.2	60	241	355
Intermediate wheatgrass	120	636	397	48	14.4	83	239	350
Crested wheatgrass	95	639	398	54	12.1	94	242	344
I & western wheatgrass	128	644	391	44	14.6	76	253	348
CRP mixture	129	632	400	47	14.5	73	232	353
Brome-alfalfa	143	636	398	48	18.0	63	239	350
<u>Leonard (Site 4)</u>								
Bromegrass [‡]	89	661	425	54	12.8	87	236	371
Intermediate wheatgrass	108	659	428	48	14.6	83	232	379
Crested wheatgrass	94	661	425	58	13.9	97	236	367
I & western wheatgrass	101	670	429	48	13.8	86	241	380
CRP mixture	106	686	453	54	14.1	70	233	399
Brome-alfalfa	107	666	438	57	15.5	88	229	380
Switchgrass [‡]	76	738	455	59	8.7	92	283	395
Reed canarygrass [‡]	105	668	433	48	13.8	63	235	386
<u>Glenfield Poor (Site 5)</u>								
Bromegrass	122	643	395	46	17.2	55	248	349
Intermediate wheatgrass	101	638	395	44	14.0	70	243	352
Crested wheatgrass	95	626	382	52	13.6	85	245	330
I & western wheatgrass	113	642	385	41	15.1	78	258	344
CRP mixture	108	632	390	44	15.2	72	241	347
Brome-alfalfa	110	665	405	49	15.8	55	260	356
<u>Carrington irrigated (Site 6)</u>								
Bromegrass	95	637	427	51	10.8	99	210	376
Intermediate wheatgrass	88	627	417	49	10.5	100	209	368
Crested wheatgrass	74	641	405	56	10.2	103	236	349
I & western wheatgrass	91	631	425	49	9.6	99	206	377
CRP mixture	94	627	437	61	12.6	96	190	376
Brome-alfalfa	101	625	423	55	11.9	94	202	368

[†] NDF = neutral-detergent fiber, ADF = acid-detergent fiber, ADL = acid-detergent lignin, N = nitrogen, TNC = total nonstructural carbohydrates, HEMI = hemicellulose (NDF-ADF), and CELL = cellulose (ADF-ADL).

[‡] Mean has only three years included.

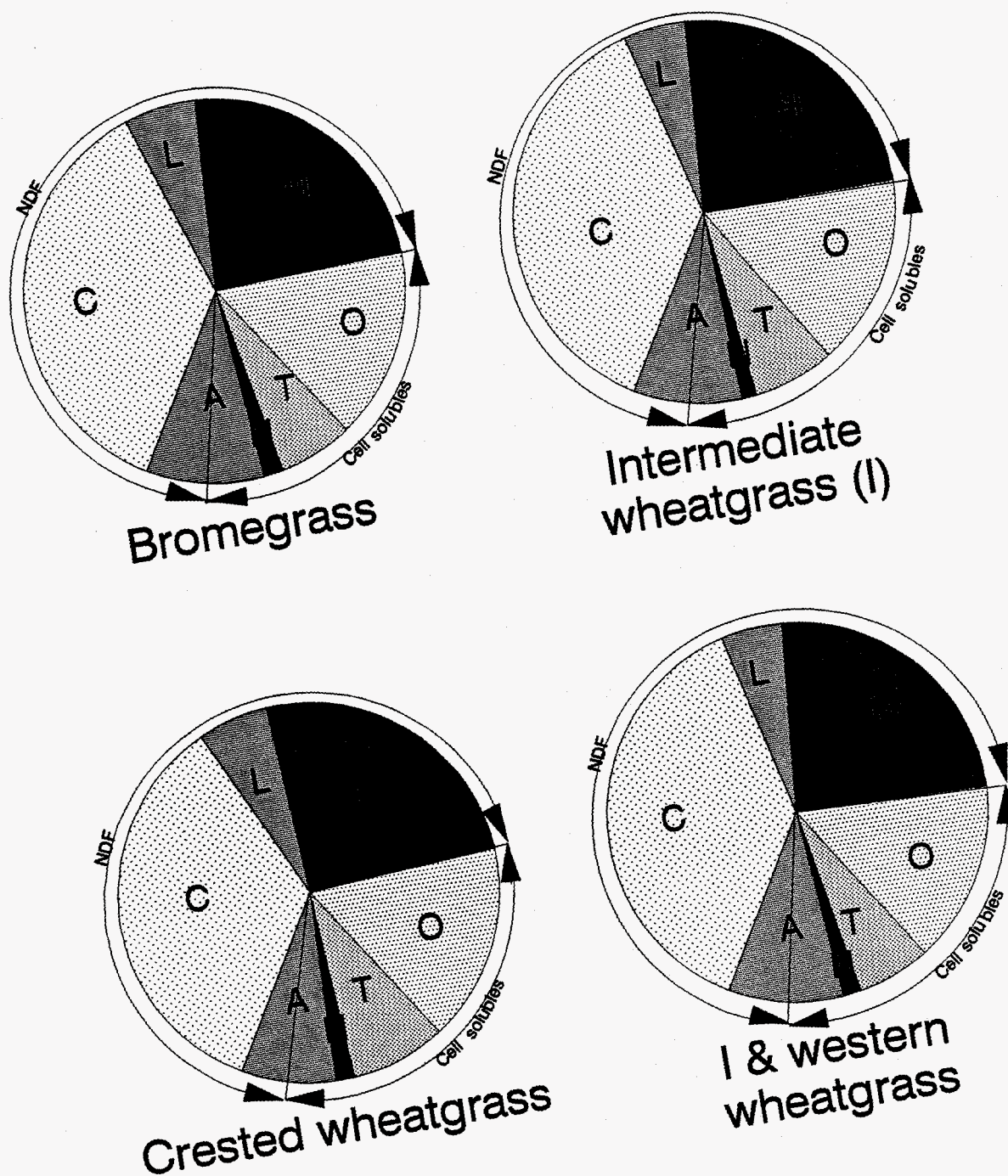
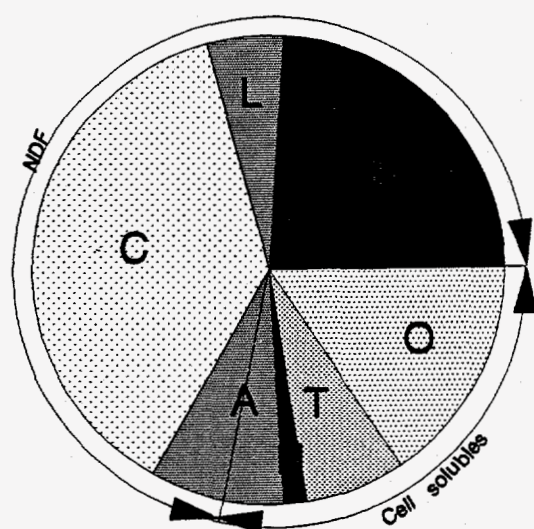
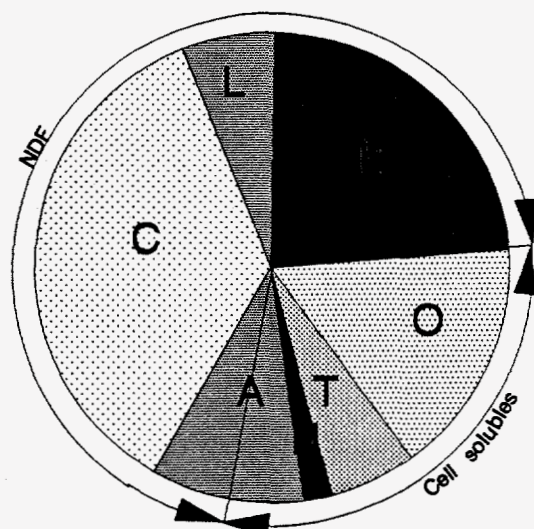


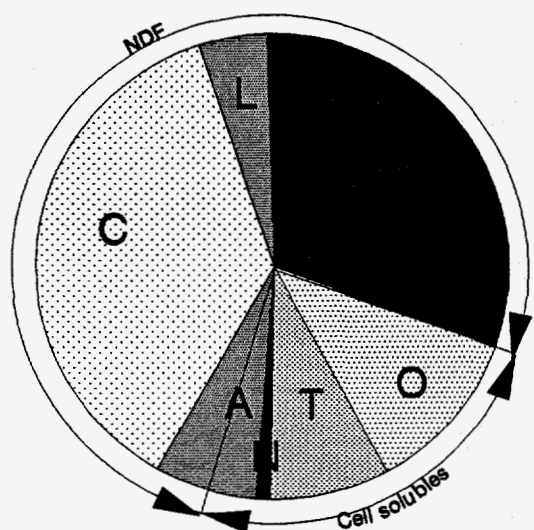
Figure 3. Chemical composition of eight perennial biomass species/mixtures at Prosper, ND, (meaned across years and N levels). C = cellulose, L = acid-detergent lignin, H = hemicellulose, O = other cell solubles, T = total nonstructural carbohydrates, N = nitrogen, A = ash.



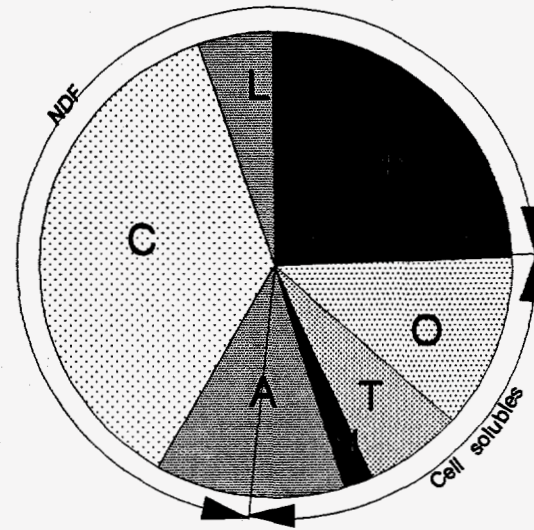
CRP mixture



Brome-alfalfa



Switchgrass



Reed canarygrass

Figure 3. (Continued).

Species differences in chemical composition within years and sites frequently were detected (Table 7) in contrast to when meaned across years (Table 6). These differences have been discussed previously by Meyer et al. (1990, 1992, 1993).

The yield of chemical components (biomass yield times concentration of each component) of perennial biomass species at six sites in 1989-92 is presented in Table 8. The absolute yields were very variable among sites and years. For example, yields of NDF ranged from 0.70 to 6.29 Mg ha⁻¹ across years and sites, or a 9-fold difference. Likewise, TNC ranged from 0.08 to 1.07 Mg ha⁻¹ and ADL ranged from 0.5 to 0.59 Mg ha⁻¹. Most chemical component yields were primarily dependent on biomass yields; although, the small differences detected in chemical composition among species/mixtures did at times contribute to yield differences (data not presented).

Corn Grain Yields

Corn for grain was included in these experiments as an environmental check. Grain yield ranged from 9.2 to 10.9 Mg ha⁻¹ at the Carrington irrigated site across the 3 test years (Table 9), about that expected at this site. Grain yields at the dryland sites were much more variable. For example, grain yields at Prosper ranged from 2.0 Mg ha⁻¹ in the 1988 dry year to 11.0 Mg ha⁻¹ on fallow in 1990. Leonard had a very similar range to that of Prosper, but grain yields were significantly lower in 1991 and 1992 at Leonard than at Prosper. Grain yields at Glenfield were at best disappointing. Grain did not set at Hettinger in 1988, 1990, and 1991 due to droughty conditions (Table 1). Grain yields were not obtained at Glenfield Good and Poor due to an undetected zinc deficiency in 1988 and 1989.

Nitrogen level and cropping system (fallow vs. wheat) management intensities rarely were significant (Table 9), in part due to the few degrees of freedom to test the cropping system effects, but also due to variable yields. Prosper in 1988 and Leonard in 1991 were the only exceptions where significance was detected.

Biomass Yield of Annuals

Biomass yield of annual herbaceous crops as affected by cropping system at two sites is presented in Table 10. Biomass yields averaged 1 to 1.2 Mg ha⁻¹ greater on fallow than on recrop wheat land at the two sites. Biomass yields were not significantly affected by the cropping system in 1991 and 1992 at both sites, but were greater on fallow than on recropped wheat land in 1990 at Leonard. Biomass yields were unaffected by the cropping system at Glenfield Poor in 1991, but were higher from recrop than from fallow at Glenfield Good in 1991 (Table 11). The reason for this last response is unclear.

Nitrogen levels above 50 kg N ha⁻¹, the lowest level used, generally did not affect the biomass yield of annual herbaceous crops at most sites or years (Table 12). Likewise, the N level X species interaction generally was nonsignificant; therefore, species results are presented at 50 kg N ha⁻¹.

Biomass yields meaned across years of annual species at 50 kg N ha⁻¹ as affected by site and cropping system is presented in Figure 4. Maximum biomass yield (16.9 Mg ha⁻¹) was obtained with forage sorghum at Carrington during 1988-91. Likewise, forage sorghum has been the highest yielding annual species on dryland averaging 16.2 Mg ha⁻¹ at Prosper on fallow during 1988-92 and the highest yielding species on recrop or fallow at Prosper, Leonard, and Glenfield Good. Sorghum X sudan has been only slightly lower yielding than forage sorghum at the high-moisture sites and higher yielding at Hettinger and Glenfield Poor, the droughty sites. This result follows what we anticipated when these experiments were planned. Foxtail millet generally has been the lowest yielding species at most sites, but may have a place where a short-season crop is needed.

Table 7. Significance of species on chemical composition of perennial biomass species at six North Dakota sites in 1989-92.

Site	Chemical component [†]							
	Ash	NDF	ADF	ADL	N	TNC	HEMI	CELL
<u>1989</u>								
Prosper	*	*	NS	*	*	NS	NS	NS
Glenfield Good	*	*	*	*	*	*	NS	*
Leonard	NS	NS	*	NS	NS	NS	NS	*
Glenfield Poor	NS	NS	NS	*	*	NS	NS	NS
Carrington irrigated	*	*	*	*	*	--	*	*
<u>1990</u>								
Prosper	*	*	*	*	*	*	NS	*
Hettinger	NS	NS	*	NS	*	*	*	NS
Glenfield Good	*	NS	*	*	*	*	NS	*
Leonard	NS	*	NS	*	NS	NS	NS	NS
Glenfield Poor	*	NS	NS	*	NS	NS	NS	NS
Carrington irrigated	*	*	NS	*	NS	*	NS	NS
<u>1991</u>								
Prosper	*	*	*	*	*	*	*	*
Hettinger	*	*	*	*	*	*	*	*
Glenfield Good	NS	*	NS	NS	*	NS	NS	NS
Leonard	*	*	NS	NS	NS	*	*	*
Glenfield Poor	NS	*	NS	*	NS	NS	NS	NS
Carrington irrigated	*	NS	*	*	NS	NS	NS	*
<u>1992</u>								
Prosper	*	*	*	*	*	NS	NS	*
Glenfield Good	NS	*	NS	*	*	NS	*	NS
Leonard	*	*	*	NS	NS	*	NS	*
Glenfield Poor	NS	NS	NS	NS	NS	*	*	NS
Carrington irrigated	*	*	*	*	NS	NS	NS	*

[†] NDF = neutral-detergent fiber, ADF = acid-detergent fiber, ADL = acid-detergent lignin, N = nitrogen, TNC = total nonstructural carbohydrates, HEMI = hemicellulose (NDF-ADF), and CELL = cellulose (ADF-ADL).

Kochia has been the most surprising species. Kochia and sweetclover were initially included as a volunteering species, but it became clear that kochia has allelopathic compound(s), which are autotoxic to the kochia plant. Biomass yield of volunteering kochia was less than half that of annually seeded kochia (data not presented). Therefore, volunteering kochia was deleted and annually seeded kochia included instead. In addition, sweetclover was not volunteering adequately so this treatment was discontinued also.

Table 8. Yield of eight chemical components of perennial biomass species at six North Dakota sites in 1989-1992 (meaned across species and N levels).

Site	Chemical component [†]							
	Ash	NDF	ADF	ADL	N	TNC	HEMI	CELL
-----Mg ha ⁻¹ -----								
<u>1989</u>								
Prosper	0.60	4.85	3.07	0.43	0.120	0.50	1.78	2.64
Glenfield Good	0.30	1.22	0.74	0.10	0.043	0.10	0.47	0.64
Leonard	1.03	6.13	4.06	0.52	0.155	0.83	2.07	3.54
Glenfield Poor	0.15	0.70	0.41	0.05	0.022	0.08	0.29	0.36
Carrington (irrigated)	0.79	5.72	3.92	0.59	0.090	---	1.80	3.33
<u>1990</u>								
Prosper	0.75	4.74	3.15	0.43	0.12	0.51	1.59	2.72
Hettinger	0.28	1.70	1.03	0.12	0.04	0.19	0.67	0.91
Glenfield Good	0.51	4.31	2.78	0.33	0.07	0.67	1.53	2.44
Leonard	1.01	6.29	4.15	0.54	0.15	1.02	2.14	3.61
Glenfield Poor	0.40	3.37	2.14	0.25	0.06	0.34	1.23	1.88
Carrington (irrigated)	0.80	6.10	4.14	0.52	0.12	1.07	1.96	3.61
<u>1991</u>								
Prosper	0.66	4.50	2.80	0.38	0.095	0.51	1.70	2.41
Glenfield Good	0.44	2.05	1.25	0.15	0.040	0.29	0.80	1.10
Leonard	0.53	4.37	2.81	0.38	0.067	0.53	1.56	2.45
Glenfield Poor	0.31	1.92	1.16	0.14	0.037	0.23	0.76	1.02
Carrington (irrigated)	0.55	3.72	2.52	0.31	0.054	0.53	1.20	2.21
<u>1992</u>								
Prosper	0.55	3.98	2.46	0.27	0.101	0.43	1.52	2.18
Glenfield Good	0.29	1.64	1.02	0.11	0.040	0.14	0.63	0.91
Leonard	0.64	4.85	3.03	0.32	0.083	0.50	1.82	2.70
Glenfield Poor	0.22	1.37	0.86	0.09	0.034	0.15	0.51	0.77
Carrington (irrigated)	0.48	3.03	1.94	0.20	0.058	0.44	1.09	1.74

[†] NDF = neutral-detergent fiber, ADF = acid-detergent fiber, ADL = acid-detergent lignin, N = nitrogen, TNC = total nonstructural carbohydrates, HEMI = hemicellulose (NDF-ADF), and CELL = cellulose (ADF-ADL).

Biomass yields of annually seeded kochia have been nearly equal to forage sorghum at Prosper and the highest yielding species at Hettinger (Fig. 3, Table 11). As a weedy species commonly found in the northern Great Plains, this species appears well adapted to droughty environments. However, it did not perform well at Leonard; although, biomass yields reported at many sites may have been reduced by inappropriate harvest dates. See the section on maturity effects latter in this report. In addition, poor stand establishment in 1991 resulted in either no observation or reduced yields from the low plant density. It is clear that additional work is needed on use of kochia as an annually seeded biomass species.

Table 9. Grain yield of corn by N level and cropping system at six North Dakota sites in 1988-92.

Site	Cropping system	Nitrogen level (kg ha ⁻¹)			LSD (0.05)	CV
		50	100	200		
-----Mg ha ⁻¹ @ 155 g kg ⁻¹ moisture-----						--%--
<u>1988</u>						
Prosper	Recrop	2.0	4.2	3.9	0.9	11.2
Leonard	Fallow	3.0	2.7	2.8	NS	14.3
Carrington	Irrigated	10.2	9.9	10.3	NS	12.2
<u>1989</u>						
Prosper	Wheat	5.9	4.4	4.3	NS	20.8
	Fallow	5.9	5.6	5.3		
Hettinger	Wheat	6.8	7.9	6.7	NS	71.2
	Fallow	4.1	3.0	5.1		
Leonard	Wheat	3.8	3.9	4.7	NS	16.9
	Fallow	5.1	4.2	5.2		
<u>1990</u>						
Prosper	Wheat	10.4	9.6	9.9	NS	11.7
	Fallow	10.2	11.0	11.0		
Glenfield Good	Fallow	9.3	9.0	9.6	NS	9.1
Leonard	Wheat	7.8	7.5	7.6	NS	9.9
	Fallow	9.3	10.8	9.4		
Glenfield Poor	Fallow	5.9	5.4	6.4	NS	11.8
Carrington	Irrigated	10.9	9.2	9.5	NS	21.1
<u>1991</u>						
Prosper	Wheat	7.7	8.7	8.6	NS	15.7
	Fallow	7.9	8.7	8.6		
Glenfield Good	Wheat	3.6	3.5	4.2	NS	23.7
	Fallow	4.3	3.6	3.5		
Leonard	Wheat	4.8	5.3	4.6	2.8	18.6
	Fallow	4.8	6.4	7.4		
Glenfield Poor	Wheat	3.7	3.6	3.7	NS	20.3
	Fallow	2.6	2.6	2.4		
Carrington	Irrigated	9.7	10.6	10.3	NS	5.8
<u>1992</u>						
Prosper	Wheat	8.1	7.7	9.8	NS	9.4
	Fallow	7.4	9.4	8.4		
Glenfield Good	Wheat	2.8	2.8	2.8	NS	21.2
Leonard	Wheat	5.5	5.5	5.1	NS	14.8
	Fallow	5.1	5.4	5.5		

Table 10. Biomass yield of annual herbaceous crops as affected by cropping system at two sites in North Dakota (mean of species and N levels).

Site	Year	Cropping system		LSD (0.05)
		Fallow	Wheat	
		-----Mg ha ⁻¹ -----		
Prosper	1989	12.0	10.6	*
	1990	19.8	17.6	*
	1991	15.3	15.1	NS
	1992	14.4	13.5	NS
	Mean	15.4	14.2	
Leonard	1989	7.8	8.4	NS
	1990	16.1	12.1	*
	1991	14.5	12.8	NS
	1992	6.9	7.8	NS
	Mean	11.3	10.3	

The highest biomass yield recorded was 23.3 Mg ha⁻¹ for forage sorghum grown at Prosper on fallow in 1990 (Table 11). Species effects within years have been discussed previously (Meyer et al., 1989-93).

Chemical Composition of Annuals

Nitrogen level and cropping system (wheat vs. fallow) at all sites and years had little effect on the chemical composition of annual biomass species (data not presented). Likewise, 2 and 3-way interactions generally were nonsignificant; therefore, all subsequent data are presented at 50 kg N ha⁻¹ and meaned across cropping systems where included.

Chemical composition of annual biomass species as influenced by environments is presented in Table 13 as a mean of species and cropping systems. Significant year X site interactions were common for many of the chemical components (data not presented); therefore, the data were not meaned across years and sites. In addition, kochia and foxtail millet were not included in all environments.

Ash, N, and TNC concentrations were quite variable while the fibrous components (NDF, ADF, ADL, hemicellulose, and cellulose) were more consistent among environments (Table 13). Ash ranged from 58 to 259 g kg⁻¹, N from 6.1 to 21.3 g kg⁻¹, and TNC from 52 to 259 g kg⁻¹. In contrast, NDF ranged from 578 to 688 g kg⁻¹, ADF from 288 to 451 g kg⁻¹, ADL from 24 to 56 g kg⁻¹, hemicellulose from 192 to 333 g kg⁻¹, and cellulose from 264 to 375 g kg⁻¹ among environments. However, a general trend was difficult to detect.

Chemical composition (meaned across years and cropping systems) of four annual species at 50 kg N ha⁻¹ and at six sites is presented in Table 14. Within a site, foxtail millet and kochia generally were higher in ash, NDF, N, and cellulose concentrations and lower in TNC concentration than the sorghums (Table 14, Fig. 5). Kochia also was higher in ADL and lower in hemicellulose concentrations than the other species. Sorghum X sudan generally was lower in ADF, ADL, and cellulose but higher in hemicellulose concentrations than forage sorghum. Chemical composition of annual species within environments has been discussed elsewhere (Meyer et al., 1990, 1992, 1993).

Table 11. Biomass yield by cropping system at 50 kg N ha⁻¹ of four annual species at six sites in North Dakota in 1988-92.

Site	Cropping system	Year	Species				Signif. of species
			Sorghum X sudan	Forage sorghum	Foxtail millet	Kochia	
			-----Mg ha ⁻¹ -----				
Prosper	Fallow	1988	9.4	13.0	-	14.4	*
		1989	11.0	13.2	10.7	11.3	*
		1990	18.5	23.3	16.5	19.4	*
		1991	15.7	15.8	14.3	-	NS
		1992	13.7	15.9	11.0	15.1	*
	Mean	13.7	16.2	13.1	15.1		
	Recrop	1989	10.9	10.2	9.6	10.8	NS
		1990	17.7	20.5	12.0	20.2	*
		1991	15.5	16.3	13.5	-	NS
		1992	11.8	12.8	10.5	13.5	*
Mean		14.0	15.0	11.4	14.8		
Hettinger	Fallow	1988	7.3	7.0	2.1	-	*
		1989	6.2	5.6	6.5	9.7	*
		1990	7.2	4.7	8.8	14.3	*
		1991	4.7	3.7	4.0	6.6	*
		Mean	6.3	5.2	5.3	10.2	
Glenfield Good	Fallow	1991	14.9	14.9	10.0	-	*
	Recrop	1989	3.6	5.8	7.0	-	**
		1990	11.5	12.2	11.2	5.8	**
		1991	16.0	15.4	8.9	10.7	*
		1992	3.3	3.2	9.0	9.6	*
		Mean	8.6	9.2	9.0	8.7	
Leonard	Fallow	1988	7.2	5.8	3.2	10.3	**
		1989	8.2	7.2	7.4	-	NS
		1990	18.0	19.9	13.3	8.8	**
		1991	11.9	20.3	11.2	-	*
		1992	9.9	7.0	8.0	6.5	*
		Mean	11.0	12.0	8.6	8.5	
	Recrop	1989	8.0	10.0	6.0	8.7	**
		1990	12.9	12.8	10.6	10.0	NS
		1991	14.0	16.6	7.7	-	NS
		1992	5.3	10.0	7.0	7.6	*
Mean		10.1	12.4	7.8	8.8		
Glenfield Poor	Fallow	1991	14.9	13.2	8.9	-	*
	Recrop	1989	5.0	4.0	6.2	7.5	*
		1990	9.0	8.7	-	6.3	NS
		1991	17.1	16.3	-	10.2	*
		Mean	10.4	9.6	-	8.0	
Carrington irrigated	Recrop	1988	18.0	19.1	10.6	8.6	**
		1989	9.5	12.1	8.3	-	NS
		1990	18.0	17.9	12.9	-	NS
		1991	17.1	18.6	14.6	-	*
		Mean	15.6	16.9	11.6	-	

*, ** Significant at $P < 0.05$ or $P < 0.01$, respectively.

Table 12. Significance of N level effect on biomass yield of annual herbaceous crops at six North Dakota sites in 1988-92 (meaned across cropping system and species).

Site	Year				
	1988	1989	1990	1991	1992
Prosper	NS	NS	NS	NS	*
Hettinger		NS	NS	NS	
Glenfield Good		NS	NS	NS	*
Leonard	NS	NS	NS	*	NS
Glenfield Poor		NS	NS	NS	
Carrington irrigated	NS	*	NS	NS	

Yields of chemical components of annuals generally had a greater number of species comparisons significant than chemical concentrations across sites and years (data not presented). Most significant component yields were related to differences in biomass yields, but significant differences among species in chemical composition contributed at times. These results are similar to the component yields of perennial species/mixtures. Yields of chemical components as affected by species within environments was discussed elsewhere (Meyer et al., 1990, 1992, 1993).

Biomass Yields on a Moisture Gradient

Scatter diagrams of biomass yields vs. growing-season (April through September) precipitation were developed for six perennial (Fig. 6) and four annual (Fig. 7) species to evaluate biomass cropping on a moisture gradient. Biomass yields were not closely associated with growing season precipitation. Coefficient of determinations range from 0.06 for kochia to 0.41 for forage sorghum (Table 15) using environments (sites and years) for the observations. Obviously, growing-season precipitation is an important factor in determining the level of biomass production, but it accounts for less than 40% of the variation noted.

Meyer et al. (1991) in a preliminary evaluation reported that coefficient of determinations ranged from 0.33 to 0.61 for the same species when evaluated within a year with 6 to 9 observations. Therefore, increasing the observations by increasing the years evaluated reduced the association between biomass yield and growing-season precipitation.

Biomass Yields of Perennials and Annuals Compared

Biomass yields of perennials and annuals were determined in separate experiments; therefore, direct comparisons are not possible. However, the perennial and annual species generally were grown in very close proximity, so a general discussion seems appropriate.

Average biomass yields across years of perennial species/mixtures (Fig. 2) at all sites rarely exceeded biomass yields of annual species (Fig. 4). The Leonard site is an exception to this general comment in that several perennials had greater biomass yields than foxtail millet and kochia under both cropping systems (Fig. 2 and 4). The production costs of a ton of perennial biomass will be cheaper than with an annual once stands are established, but the superior yields produced by annuals will probably make annuals cheaper per ton of biomass.

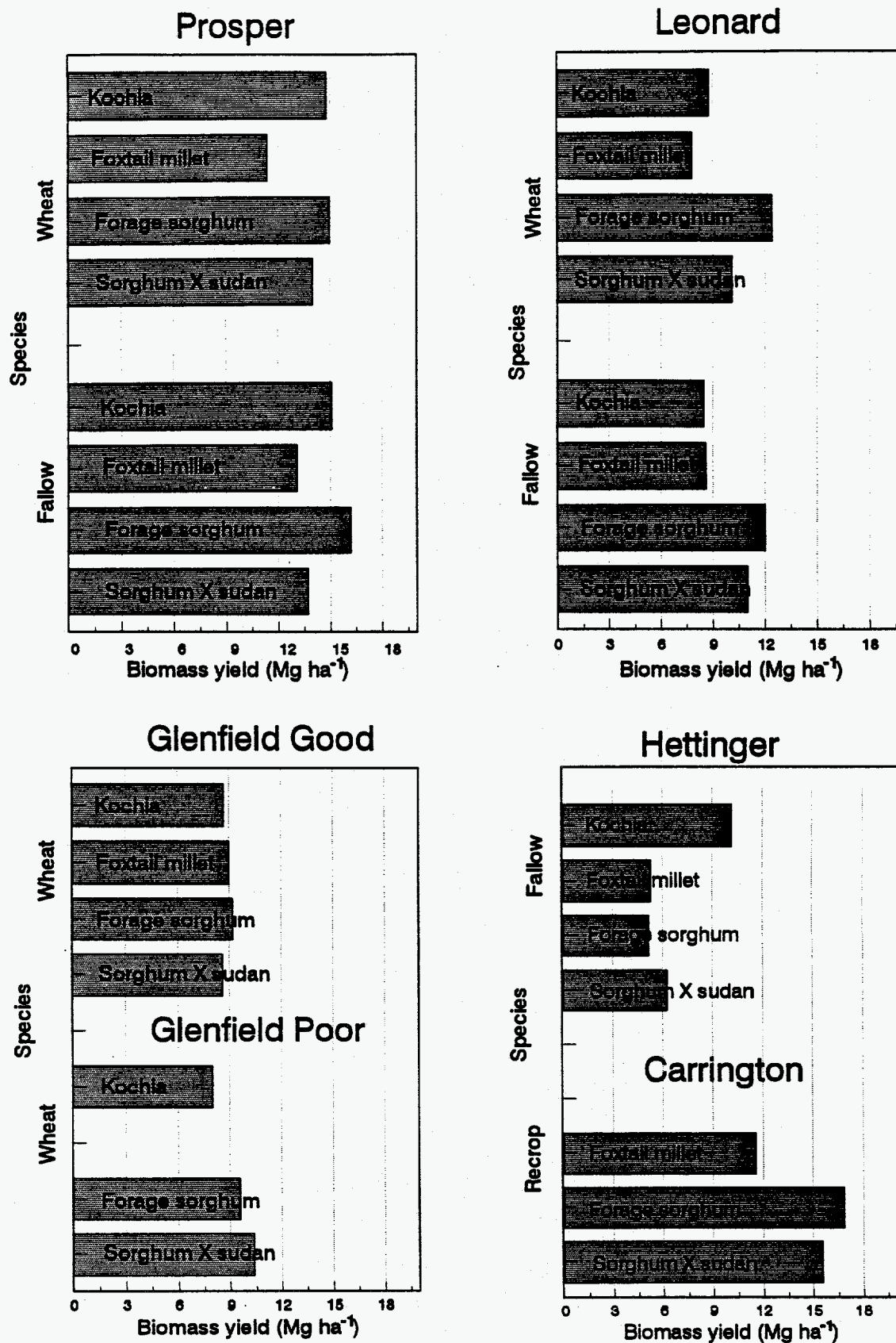


Figure 4. Biomass yields of annual species at 50 kg N ha⁻¹ at six North Dakota sites (meaned across years).

Table 13. Chemical composition of annual biomass species at six North Dakota sites in 1988-92 (mean of species and cropping system at 50 kg N ha⁻¹).

Site	Chemical component [†]							
	Ash	NDF	ADF	ADL	N	TNC	HEMI	CELL
-----g kg ⁻¹ dry weight-----								
<u>1988</u>								
Prosper	79	578	306	35	12.0	259	272	271
Hettinger	106	603	301	36	21.3	170	302	265
Leonard	83	637	335	38	17.0	171	302	296
Carrington irrigated [‡]	80	546	352	53	11.6	94	195	299
<u>1989</u>								
Prosper	91	632	347	39	13.8	58	285	308
Hettinger	94	610	310	38	20.2	78	301	271
Glenfield Good	108	642	345	28	19.2	52	297	317
Leonard	60	612	324	30	13.0	93	288	294
Glenfield Poor	112	644	343	31	19.5	68	302	311
Carrington irrigated [‡]	79	615	371	43	9.0	--	244	328
<u>1990</u>								
Prosper	102	628	407	56	10	73	221	351
Hettinger	259	582	390	39	18	69	192	350
Glenfield Good	134	659	451	53	9	107	208	308
Leonard	76	617	388	55	11	88	230	333
Carrington irrigated [‡]	98	590	369	45	11	111	221	324
<u>1991</u>								
Prosper	93	609	397	46	9.3	114	212	351
Hettinger	98	621	288	24	20.4	105	333	264
Glenfield Good [§]	71	609	328	35	9.3	139	281	293
Leonard	58	688	421	49	6.1	105	267	372
Glenfield Poor	82	633	367	40	11.0	98	266	327
Carrington irrigated [‡]	79	631	398	50	11.1	118	232	348
<u>1992</u>								
Prosper	91	629	413	38	11.2	99	215	375
Glenfield Good [§]	102	656	376	30	14.7	71	280	346
Leonard	76	656	405	40	10.7	68	251	365

[†] NDF = neutral-detergent fiber, ADF = acid-detergent fiber, ADL = acid-detergent lignin, N = nitrogen, TNC = total nonstructural carbohydrates, HEMI = hemicellulose (NDF-ADF), and CELL = cellulose (ADF-ADL).

[‡] Recrop only, no fallow and no kochia.

[§] Included only sorghum X sudan and forage sorghum, no foxtail millet.

Table 14. Chemical composition of annual biomass species at 50 kg N ha⁻¹ at six North Dakota sites (meaned across years and cropping systems).

Species	Chemical component [†]							
	Ash	NDF	ADF	ADL	N	TNC	HEMI	CELL
-----g kg ⁻¹ dry weight-----								
<u>Prosper (Site 1)</u>								
Sorghum X sudan	78	598	369	54	9.9	150	229	326
Forage sorghum	82	581	337	36	10.7	150	245	300
Foxtail millet [‡]	123	670	428	48	12.9	57	242	380
Kochia [‡]	100	638	418	66	16.4	52	220	352
<u>Hettinger (Site 2)</u>								
Sorghum X sudan [‡]	127	603	317	31	18.5	144	259	302
Forage sorghum [‡]	163	618	333	31	19.8	127	285	302
Foxtail millet [‡]	123	619	317	34	20.3	107	302	283
Kochia [§]	156	489	280	53	25.5	91	209	227
<u>Glenfield Good (Site 3)</u>								
Sorghum X sudan [‡]	106	650	396	40	11.7	83	255	355
Forage sorghum [‡]	97	630	345	31	13.0	89	285	313
Foxtail millet [‡]	122	666	396	41	13.5	51	271	355
Kochia [‡]	111	622	391	62	15.6	61	231	328
<u>Leonard (Site 4)</u>								
Sorghum X sudan	54	636	374	40	10.6	129	263	334
Forage sorghum	60	613	347	32	9.6	134	266	315
Foxtail millet	86	668	396	47	11.2	95	272	348
Kochia	105	614	393	62	16.5	42	221	331
<u>Glenfield Poor (Site 5)</u>								
Sorghum X sudan [‡]	83	635	356	36	14.0	95	279	321
Forage sorghum [‡]	96	630	349	30	14.2	102	281	319
Foxtail millet [‡]	110	644	379	39	15.1	76	265	341
Kochia [‡]	100	583	352	62	15.9	39	231	290
<u>Carrington irrigated (Site 6)</u>								
Sorghum X sudan [‡]	75	573	380	49	8.0	134	194	331
Forage sorghum [‡]	74	566	338	41	9.5	135	229	297
Foxtail millet [‡]	105	645	409	52	11.2	78	236	357

[†] NDF = neutral-detergent fiber, ADF = acid-detergent fiber, ADL = acid-detergent lignin, N = nitrogen, TNC = total nonstructural carbohydrates, HEMI = hemicellulose (NDF-ADF), and CELL = cellulose (ADF-ADL).

[‡] Four-year mean (1988-91, or 1989-1992).

[§] Three-year mean (1989-91).

[‡] Two-year mean (1989, 1991).

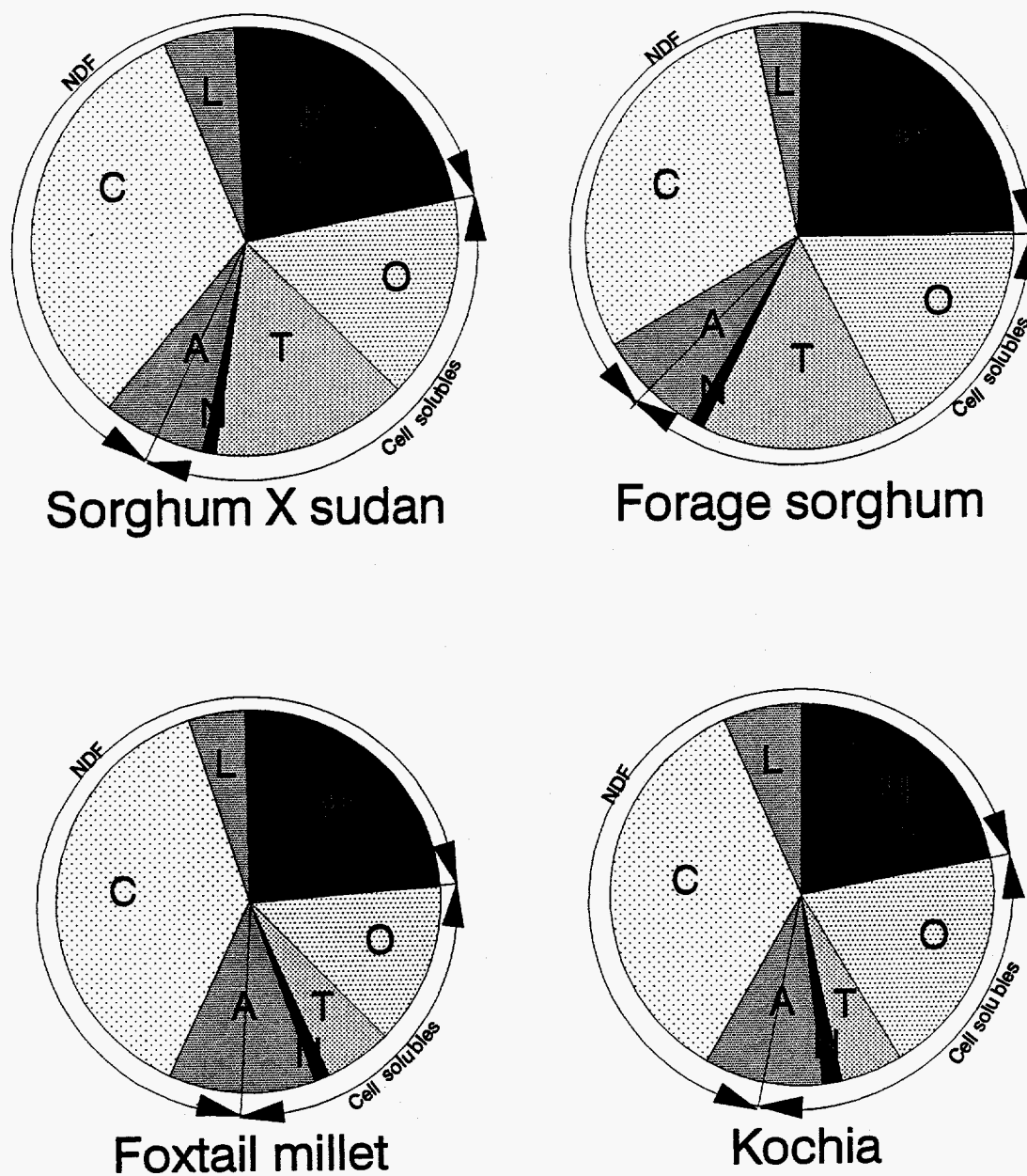


Figure 5. Chemical composition of four annual biomass species at 50 kg N ha⁻¹ at Prosper, ND, (meaned across cropping system and N levels). C = cellulose, L = acid-detergent lignin, H = hemicellulose, O = other cell solubles, T = total nonstructural carbohydrates, N = nitrogen, A = ash.

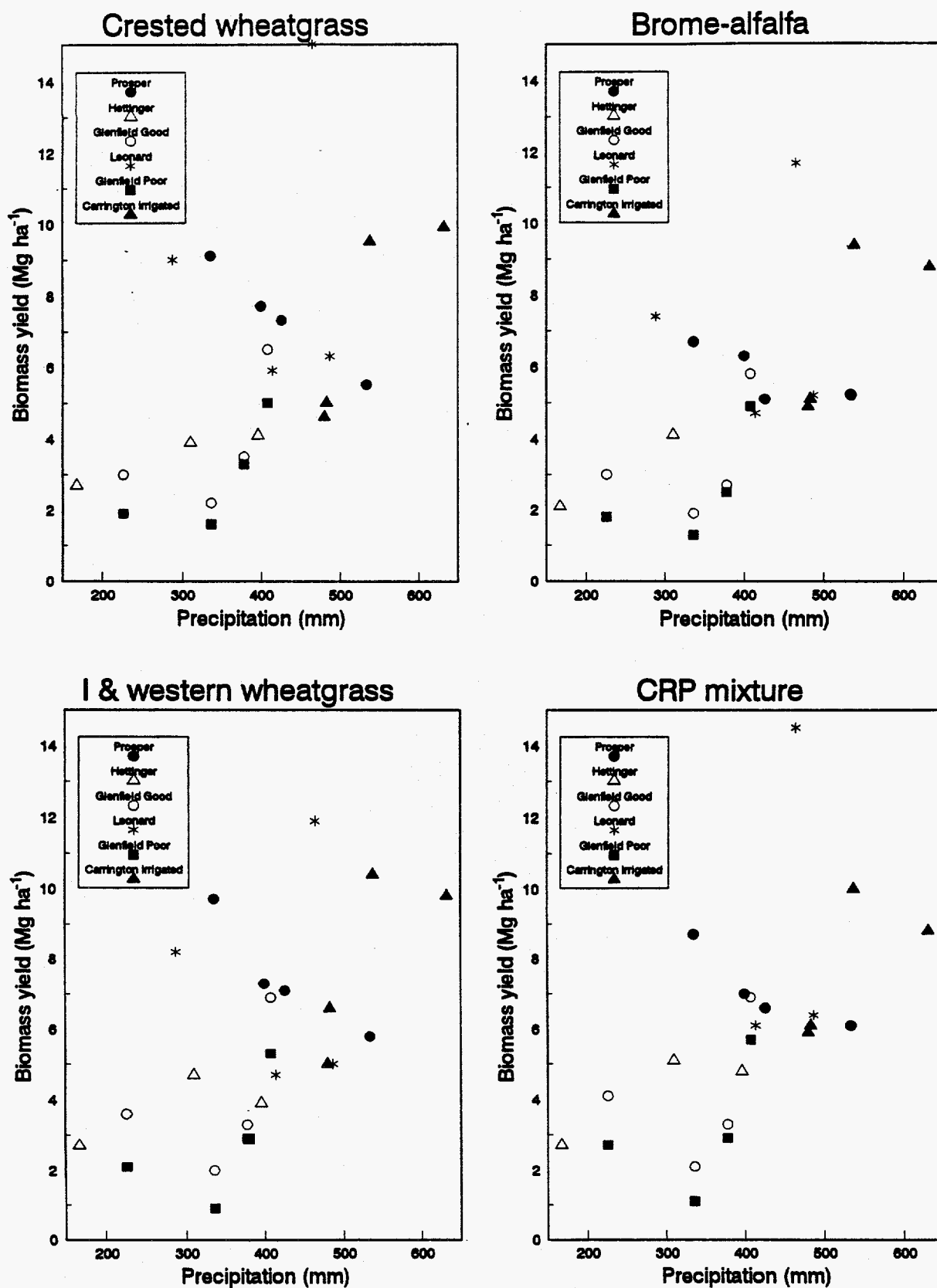


Figure 6. Biomass yields for six perennial species/mixtures plotted versus growing-season precipitation. Each symbol represents a biomass yield meaned across N levels within a site and year.

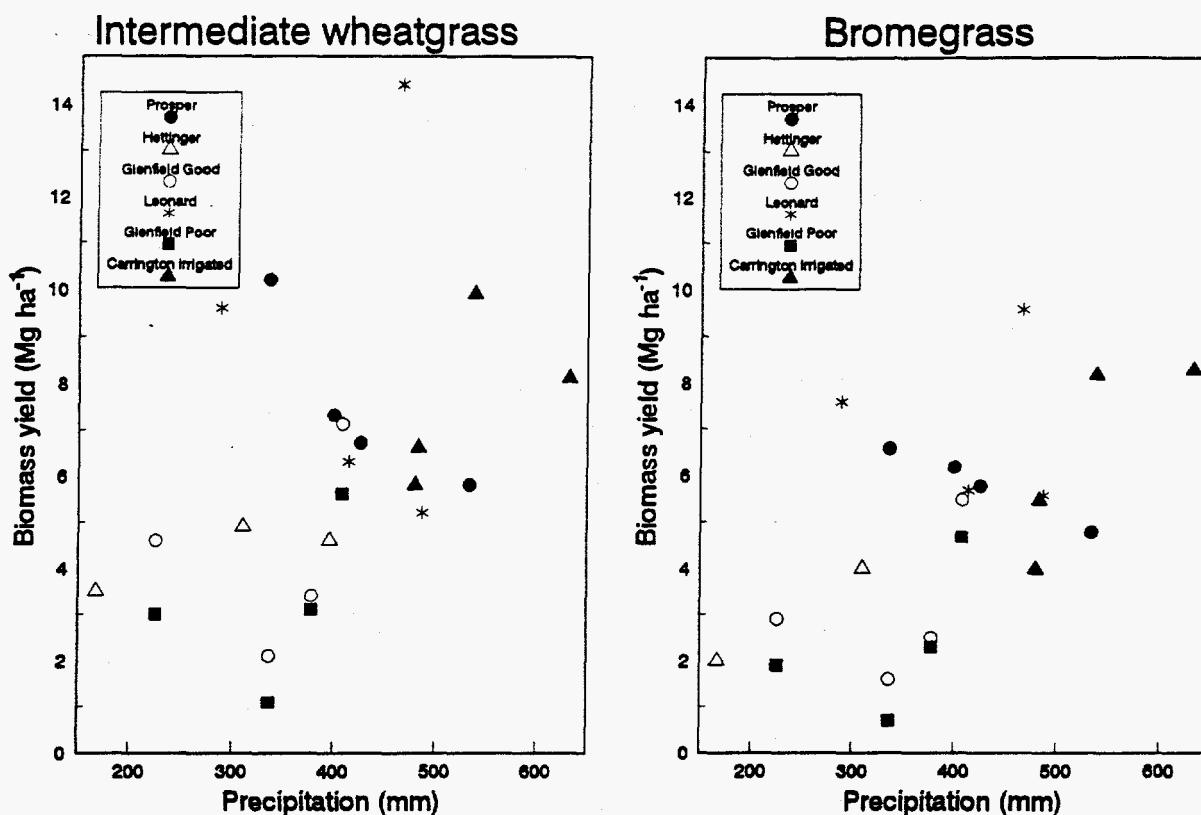


Figure 6. Continued.

Table 15. Linear regression equations of biomass yield (Mg ha^{-1}) (meaned across N level) versus growing-season precipitation (mm) using an environment as the observation.

Species/mixture	No. observations	Regression equation	r^2
<u>Perennials</u>			
Intermediate wheatgrass (I)	23	$y = 1.57 + 0.0113x$	0.17
Bromegrass	22	$y = -0.25 + 0.0129x$	0.36
Crested wheatgrass	23	$y = -0.27 + 0.0153x$	0.26
Brome-alfalfa	22	$y = -0.62 + 0.0144x$	0.37
I & western wheatgrass	23	$y = -0.16 + 0.0147x$	0.30
CRP mixture	22	$y = 0.65 + 0.0136x$	0.23
<u>Annuals</u>			
Sorghum X sudan	19	$y = -0.82 + 0.0301x$	0.33
Forage sorghum	19	$y = -1.42 + 0.0338x$	0.41
Foxtail millet	17	$y = 5.44 + 0.0102x$	0.16
Kochia	13	$y = 8.86 + 0.0027x$	0.01

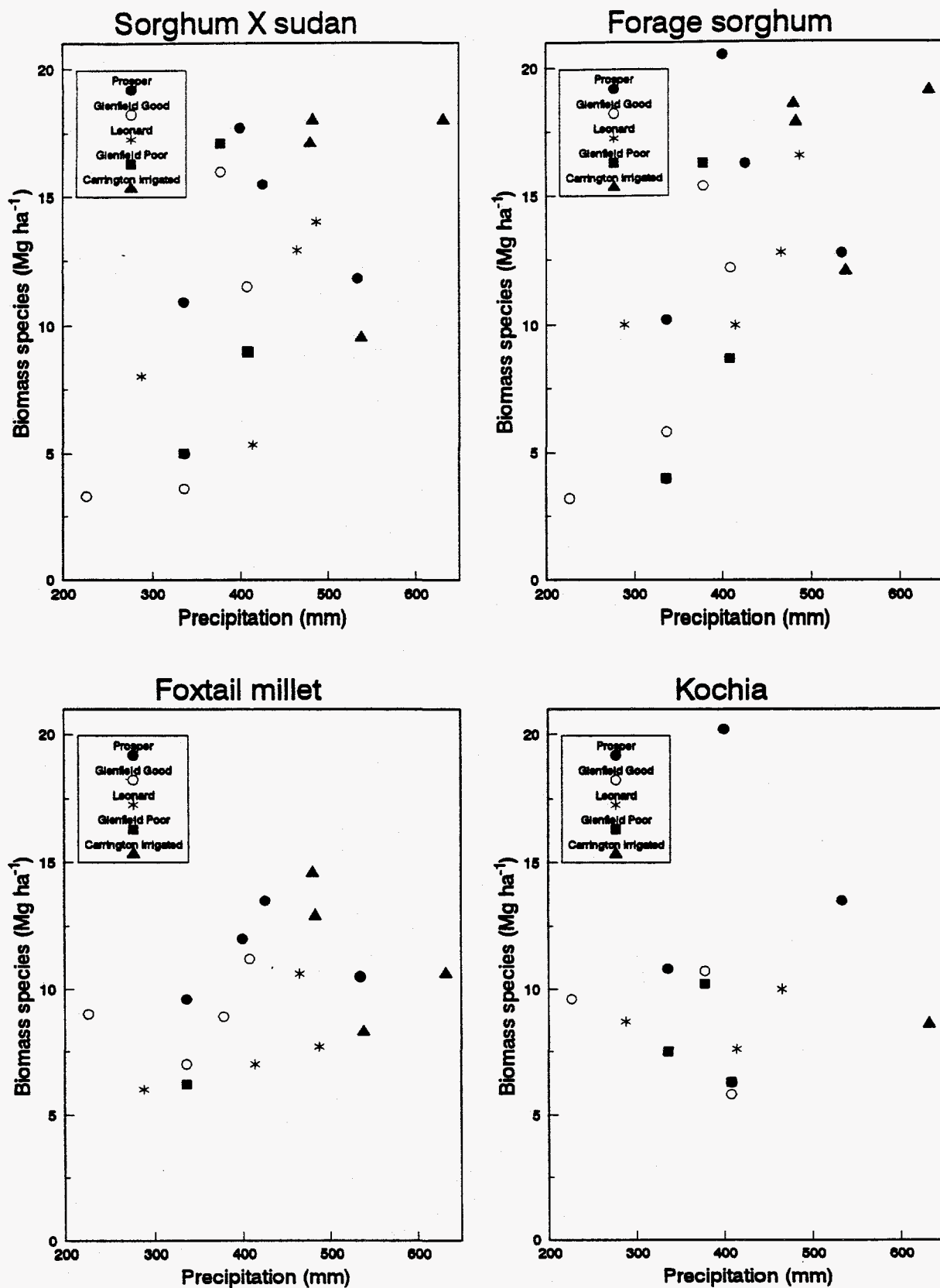


Figure 7. Biomass yields for four annual species plotted versus growing-season precipitation. Each symbol represents a biomass yield at 50 kg N ha⁻¹ within a site and year.

Biomass Cropping on Normally Fallowed Land

Legume biomass yields on normally fallowed land in 1990 ranged from 2.1 to 3.9 Mg ha⁻¹ for 1- and 2-cut alfalfa and 2.7 Mg ha⁻¹ for 1-cut sweetclover (Table 16). The poor alfalfa yield was due to severe alfalfa leafhopper infestations on both growths, the first time in 20 years an economic infestation occurred. Biomass yields would normally have been nearly double with the precipitation received without the leafhopper infestation. Sweetclover biomass yields were about 1 Mg ha⁻¹ less than expected, possibility due to weed competition.

Table 16. Grain yield of Hazen barley in 1991 following a legume biomass crop in 1990 at Carrington, ND.

1990 cropping treatment	Fall tillage	1990 biomass yield	N level (kg ha ⁻¹)			Mean
			0	75	150	
			-----kg ha ⁻¹ @ 120 kg ha ⁻¹ moisture-----			
		Mg ha ⁻¹				
Wheat + 100 N	+	-	2307	3280	3220	2936
Fallow	+	-	2515	2918	2447	2628
1-cut alfalfa [†]	+	2.1	2323	2735	3203	2754
1-cut alfalfa	-	2.4	2414	3891	2501	2602
2-cut alfalfa	+	3.2	2155	3134	2804	2766
2-cut alfalfa	-	3.9	2379	2167	2837	2461
1-cut sweetclover	+	2.7	2310	2891	3249	2817
1-cut sweetclover	-	2.8	2515	3616	3216	3116
GM sweetclover [‡]	+	2.7	2787	3309	3296	3131
GM sweetclover	-	2.6	2838	2654	2659	2717
Wheat + 100 N	-	-	3024	3330	3292	3215
Mean			2438a [§]	2967b	2960b	2794
LSD (0.05)		0.7		NS		463
CV (%)		14.5		18.2		17.1

[†] Nitro alfalfa harvested for hay on 15 August, second harvest date was 30 September.

[‡] GM = green manured.

[§] Means followed by similar letters are not significantly different at $P < 0.05$.

Barley grain yields meaned across biomass treatments and tillage increased from 2438 to 2967 kg ha⁻¹ with application of 75 kg N ha⁻¹. Additional N additions did not increase grain yield.

Barley grain yield (meaned across N levels) was the highest following no-till wheat-barley rotation, primarily due to superior yield of the unfertilized treatment (Table 16). Apparently, enough N was carried over from the previous crop for near maximum grain yield. Grain yields of the 1-cut no-till and green-manured, tilled sweetclover treatments were similar to the no-till wheat-barley rotation and greater than the conventional-tilled wheat-barley rotation. The low grain yield following no-till green-

manured sweetclover may have been due to a tie up of N in decomposition of the residue that was incorporated with spring tillage. These responses are similar to data reported by Meyer (1987) and Badaruddin and Meyer (1989).

Barley grain yields following 1- or 2-cut alfalfa were less than the wheat-barley rotation conventionally tilled and about equal to fallow (Table 16). It is unclear why the fallow treatment yielded less than the wheat-barley rotation unless moisture accumulation over the winter was a major factor or moisture storage on fallow was negligible due to tillage for weed control.

Reduced tillage results were erratic. No-till wheat-barley tended to yield greater than conventional-tilled, and no-till 1-cut sweetclover was slightly greater yielding than conventional-tilled. However, no-tilled 1- or 2-cut alfalfa was lower yielding than like treatments tilled.

Nonfertilized wheat grain yield was highest following the 1-cut sweetclover no-till treatment (Table 17). Most other treatments were quite similar.

Wheat grain yields (meaned across cropping systems) increased about 300 kg ha⁻¹ with application of 75 kg N ha⁻¹ (Table 17). Highest grain yields at the medium fertilization level occurred on wheat following wheat treatment. This is contrary to most previous results (Meyer, 1987; Badaruddin and Meyer, 1989) from legume cropping systems in North Dakota where normally fertilized wheat on wheat grain yield was nearly equal to nonfertilized grain yields following legumes either hayed or green-manured. One possible explanation for these results might be more water use by the legumes than wheat in 1990. An additional unit of N generally decreased or only slightly increased grain yields compared with 75 kg N ha⁻¹ except on 1-cut alfalfa with fall incorporation. The reason for this high grain yield is unclear.

These 1-year data suggest that a leguminous biomass crop (especially sweetclover) could be removed without reducing subsequent crop productivity substantially. However, additional work is needed on stand establishment of the leguminous biomass species. Inadequate stands to perform this experiment were obtained in 2 out of 3 years, partially due to two very dry establishment seasons. However, no-till establishment of legumes may allow consistent stand establishment in all but the driest environments.

Economic Analysis of Biomass Cropping

The first phase to evaluate the economic feasibility of biomass cropping was to develop model farms and enterprise budgets for three areas (Johnson et al., 1990). A linear programming model was used to analyze the impact of producing herbaceous energy crops on the model farms. Returns over variable costs were determined for all herbaceous biomass crops and conventional crops (Johnson et al., 1993a). The following is the abstract of the final report; see Johnson et al. (1993b) for more details.

The economics of producing herbaceous biomass crops were evaluated for three regions of North Dakota. Typical farms were modeled for eastern (Cass County), central (Foster County), and western (Adams County) North Dakota. At a \$35-per-ton price, biomass crops were included in profit-maximum farm plans in all three areas. The increase in net income through introduction of biomass crops was substantial (up to \$20,000) in Cass County. Kochia was the biomass crop included in the farm plan in all regions. When kochia is excluded, sudan/sorghum (Adams), forage sorghum (Cass), and sorghum X sudan (Foster) were the most profitable biomass crops. Including biomass crops changed

Table 17. Grain yield of Stoa wheat in 1991 following a legume biomass crop in 1990 at Carrington, ND.

1990 cropping system	Fall tillage	1990 biomass yield	N level in 1991 (kg ha ⁻¹)			Mean
			0	75	150	
		---Mg ha ⁻¹ ---	-----kg ha ⁻¹ @ 140 g kg ⁻¹ moisture-----			
Wheat + 100 N	+	-	1862	2795	2510	2389
Fallow	+	-	2089	2085	1856	2009
1-cut alfalfa	+	2.1	2058	2481	3020	2520
1-cut alfalfa	-	2.4	1899	2194	2225	2106
2-cut alfalfa	+	3.2	1914	2607	2049	2190
2-cut alfalfa	-	3.9	2197	2109	2318	2208
1-cut sweetclover	+	2.7	1718	2385	2393	2166
1-cut sweetclover	-	2.8	2447	2643	2238	2443
GM sweetclover [†]	+	2.7	2180	2741	2234	2385
GM sweetclover	-	2.6	1919	2148	2177	2081
Mean			1951a [§]	2286b	2215b	
LSD (0.05)		0.7		790		NS
CV (%)		14.5		20.3		26.3

[†] Nitro alfalfa harvested for hay on 15 August, second harvest date was 30 September.

[‡] GM = green manured.

[§] Means followed by a similar letter are not significantly different at $P < 0.05$.

the labor distribution but did not necessarily eliminate high labor-use periods. At lower biomass prices, production would be eliminated first on the Cass County farm followed by the Foster and Adams Counties model farms.

Add-on Experiments

Maturity Effects on Biomass Yield of Kochia

Kochia in 1989 was harvested in August to prevent seed production so it would not cause a weed problem. But, results in 1989 suggested that the early harvest reduced the biomass yield. Therefore, our objective of these experiments were to determine the influence of maturity on biomass yields of kochia.

Biomass yields dropped sharply in 1990 when harvested 19 days after a killing frost (Table 18). Ash and ADL concentrations increased and N concentration tended to decrease with maturity. Cellulose, hemicellulose, NDF, and ADF concentrations changed little with maturity from mid-August through October.

Table 18. Biomass yield and chemical composition of seeded kochia harvested at four maturity dates at Prosper, ND, in 1990.

Harvest date	Dry matter concentration	Biomass yield	Ash	NDF	ADF	ADL	N	HEMI	CELL
	---g kg ⁻¹ ---	---kg ha ⁻¹ ---	-----g kg ⁻¹ dry weight-----						
9 August	303	11.8	77	671	480	63	16	191	417
22 August	322	12.6	63	694	512	69	13	182	444
5 August	580	15.5	101	698	483	72	14	215	410
22 October [†]	685	6.8	91	696	498	73	12	198	425
LSD (0.05)	2.5	0.9	2.6	NS	NS	Ns	NS	NS	NS
CV (%)	2.8	4.2	22.7	11.3	11.2	7.0	31.9	26.0	12.3

[†] Frost (-7.7°C) occurred 3 October 1990.

This experiment was seeded at Prosper and Leonard in 1991, but the kochia seed source in 1991 did not establish adequate stands. It is unclear why the seed was poor, since we used the same methods of obtaining seed as previous years.

A native stand from a sparse 1991 stand was sampled about every 10 days starting July 10 in 1992. Biomass yields increased from 29 July (stem elongation) to 17 September (maturing seed) (Table 19). Biomass yield dropped 6.6 Mg ha⁻¹ following a -2.2°C frost on 22 September and a -5.5°C frost on 28 September due to seed and leaf loss. Likewise, biomass yield dropped 3.4 Mg ha⁻¹ following the frost in a late spring-seeded experiment (Table 20). Kochia must be harvested for biomass prior to frost to prevent sizable yield losses!

Biomass yield of kochia in the native stand (Table 19) increased 4.8 Mg ha⁻¹ from early to mid September, much of it due to seed production. If kochia is used as a biomass species, seed drop must be prevented in order to keep it from infesting subsequent crops. Therefore, optimum harvest time will be 2 to 3 weeks prior to normal first frost.

Fibrous component (NDF, ADF, ADL, hemicellulose, and cellulose) concentrations increased and N, TNC, and ash decreased as kochia matured in both 1992 experiments (Tables 19 and 20). These data are in contrast to the 1990 (Table 18) data where fibrous components changed little with maturity. The reason for differences in chemical composition among the years is unclear, but 1992 data is more what would be anticipated from a maturing crop.

Effects of Biomass Cropping on Subsequent Crop Yields

Our objective was to determine the "cost" of biomass cropping on normally fallowed lands, i.e., not having fallow land for subsequent cropping. Fallow and wheat treatments were included with the annual experiments at Prosper and Leonard in 1991. 'Grandin' spring wheat was seeded during April 1992 across all species. During May, it became obvious that this experiment failed due to atrazine carryover. Unknown to us, the previous research specialist had hand-sprayed green and yellow foxtail with atrazine a second time, which increased atrazine carryover. The carryover was enough to kill the

Table 19. Biomass yield and chemical composition of kochia (native stand) at six maturity stages at Prosper, ND, in 1992.

Harvest date	Biomass yield	Chemical component [†]							
		Ash	NDF	ADF	ADL	N	TNC	HEMI	CELL
	Mg ha ⁻¹	-----g kg ⁻¹ dry weight-----							
10 July	-- [‡]	169	481	313	45	32	36	169	267
20 July	--	181	547	388	44	24	40	159	344
29 July	10.2	102	561	361	54	24	37	201	306
12 August	12.2	85	639	427	66	19	38	213	361
21 August	11.6	82	652	444	69	16	51	208	375
3 September	13.6	81	635	431	72	18	46	204	360
17 September	18.4	82	668	471	72	15	36	197	400
30 September	11.8	70	775	542	80	8	26	233	462
LSD (0.05)	3.8	26	77	72	11	3	NS	26	72

[†] NDF = neutral-detergent fiber, ADF = acid-detergent fiber, ADL = acid-detergent lignin, N = nitrogen, TNC = total nonstructural carbohydrate, HEMI = hemicellulose (NDF-ADF), and CELL = cellulose (ADF-ADL).

[‡] No yield taken.

Table 20. Biomass yield and chemical composition of kochia at four harvest dates at Prosper, ND, in 1992 (spring-seeded stand).

Harvest date	Biomass yield	Chemical composition [†]							
		Ash	NDF	ADF	ADL	N	TNC	HEMI	CELL
	Mg ha ⁻¹	-----g kg ⁻¹ dry weight-----							
3 September	8.9	9.6	587	382	61	20	49	205	321
17 September	8.5	7.8	650	439	70	14	45	211	370
30 September	5.1	7.2	756	545	76	9	20	211	469
15 October	4.2	7.0	769	538	78	9	24	231	459
LSD (0.05)	1.0	1.5	54	61	9	4	24	18	54

[†] NDF = neutral-detergent fiber, ADF = acid-detergent fiber, ADL = acid-detergent lignin, N = nitrogen, TNC = total nonstructural carbohydrate, HEMI = hemicellulose (NDF-ADF), and CELL = cellulose (ADF-ADL).

emerging wheat plants for about 15 cm over the old sorghum and corn rows. As a result, the experiment was abandoned at both sites.

Maturity Effects on Stand Maintenance of Perennial Grasses

The objective of these preliminary experiments was to evaluate the effect of delayed harvest typical of biomass cropping on yield and stand maintenance in herbaceous perennial biomass species. Biomass yields of brome grass, crested wheatgrass, and intermediate wheatgrass were unaffected by harvest date at Fargo, ND, in 1992 (Table 21). Increasing N level from 0 to 150 kg ha⁻¹ increased biomass yields 130% as a mean of species in the 5th year of fertilization. No lodging occurred in this experiment and in a similar experiment at Carrington, ND, in 1992 (data not presented). Likewise, no differences in stands could be detected by harvest date; although, ground cover was slightly greater in the nonfertilized compared with highly fertilized plots.

An old brome grass sod fertilized with six levels of N since 1954 was harvested for biomass determination at two dates during 1990-92. Average biomass yields have been slightly higher when harvested 3 to 4 weeks after anthesis than harvesting at anthesis (Table 22). Biomass yields increased with N level up to 74 to 149 kg ha⁻¹, but decreased with increasing N level when harvested at anthesis. This decrease is due to a small stand loss in about 1 out of 4 years. However, little stand deterioration has occurred in plots fertilized with 74 or 149 kg N ha⁻¹, indicating that stand deterioration should not be a problem at economically productive levels of N fertilization.

Stand maintenance was evaluated following 4 years of biomass cropping at the six sites. Little deterioration of stand occurred at any site (data not presented)! Stands actually improved at the two Glenfield sites for all rhizomatous species. Less lodging occurred at Leonard than at Carrington irrigated and Prosper sites. As a result, no stand deterioration was observed at Leonard. Extensive lodging of cool-season species/mixtures (reed canarygrass excepted) occurred each year at Prosper and Carrington irrigated. If harvest of these species had been delayed into August or September, we are convinced that significant stand loss would have occurred. But, with the harvest date selected, little deterioration of stand occurred. Even plots showing slight stand deterioration at 200 kg N ha⁻¹ had better ground cover than the long-term fertilization experiment with brome grass harvested at anthesis (Table 22).

Table 21. Biomass yield of three grass species as affected by harvest date and N level at Fargo, ND, in 1992.

Harvest date	N level	Species			Mean
		Brome grass	Crested wheatgrass	Intermediate wheatgrass	
	--kg ha ⁻¹ --	-----Mg ha ⁻¹ -----			
9 July	0	4.01	3.28	2.42	3.24m [†]
	37	6.51	4.45	3.98	4.98n
	75	8.42	5.59	5.95	6.66op
	150	7.40	5.14	7.26	6.60op
31 July	0	3.33	2.23	2.58	2.71m
	37	6.57	3.20	5.06	4.94n
	75	7.43	3.96	7.12	6.17no
	150	8.34	6.38	7.80	7.51p
Mean	0	3.67	2.75	2.50	2.98a
	37	6.54	3.82	4.52	4.96b
	75	7.93	4.78	6.54	6.41c
	150	7.87	5.76	7.53	7.05c

[†] Means followed by similar letters within letter groups a-c and m-p are not significantly different at $P < 0.05$.

Table 22. Biomass yield of brome grass as affected by N level and harvest date at Fargo, ND, in 1990-92.

N level	Anthesis				3-4 weeks after anthesis			
	6-26-90	6-27-91	7-6-92	Mean	7-24-90	7-19-91	7-31-92	Mean
kg ha ⁻¹	-----Mg ha ⁻¹ -----							
0	2.85	3.07	1.60	2.51	3.22	2.92	1.89	2.68
37	4.39	5.18	2.49	4.02	4.51	4.37	2.73	3.87
74	5.60	5.11	4.72	5.14	6.81	5.78	5.08	5.89
149	5.70	5.69	5.71	5.70	5.66	5.67	5.01	5.45
224	4.91	6.08	5.20	5.40	6.20	5.70	5.77	5.89
298	5.47	4.83	5.51	5.27	7.33	4.90	5.42	5.88
LSD (0.05)	0.62	0.36	0.88	0.38	0.87	0.69	0.75	0.39

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Biomass cropping in the northern Great Plains has real potential! Environments sampled ranged from the relatively cool, wet year in 1992 to the very dry years of 1988 and 1989. They also included the exceptional yielding year of 1990 at Prosper and Leonard, and 1991 at Glenfield and Leonard. Therefore, reported biomass yields should be indicative of the variation expected if biomass cropping occurred in the northern Great Plains.

Greatest biomass yields were obtained from forage sorghum at Prosper and Carrington irrigated when meaned across years. Sorghum X sudan frequently yielded greater than forage sorghum in drier environments. Annually seeded kochia frequently was competitive in biomass yield to the sorghums, and occasionally was the highest yielding species, especially under drought stress. Foxtail millet generally was lower yielding than other annuals.

Perennial species generally did not have the biomass yield potential of the annuals. However, the 1.2 million hectares of CRP land primarily established with the CRP mixture is a potential vast resource for biomass production. Intermediate wheatgrass, the CRP mixture (dominated by intermediate), and reed canarygrass (limited observations) generally were the highest yielding cool-season species/mixtures.

We obtained only limited data on switchgrass due to its very poor establishment. But, where adequate stands were obtained (Leonard and Prosper), switchgrass showed its potential as a promising biomass species in the northern Great Plains. We conclude that additional research on switchgrass, especially on stand establishment, should be funded in the northern Great Plains to more fully evaluate its potential as a biomass species.

Biomass yields of perennials were unaffected by N level during the first two years of production, but were increased by N fertilization during the third and fourth years of production (switchgrass was an exception). Biomass yields of annuals rarely were increased by an additional unit of N above 50 kg ha⁻¹. Crop-recrop comparison generally was nonsignificant; therefore, growing biomass on recrop land is the best option even though biomass yields might be slightly lower in some years.

The environment (site and year) had a strong influence on the chemical composition of both annual and perennial species, and tended to be a more important factor than N level, cropping system, or species. The one exception to this comment was the differences in chemical composition of warm- vs. cool-season perennials.

Biomass cropping was economically feasible in the three study areas evaluated when biomass was valued at \$39.2 Mg⁻¹ and marketing-year average price for competing crops was used. One or more biomass crops had a higher net return than the area's best conventional crop. Kochia and forage sorghum were generally the most profitable biomass species. Switchgrass, included only in the Red River Valley comparisons, was more profitable than the common small grains grown in the area. We conclude that biomass cropping is an economically viable alternative crop, especially in the Hettinger and Glenfield areas (the lowest yielding), since few cropping alternatives exist.

Kochia was the most profitable biomass species primarily due to very low input cost. No herbicide was needed for weed control and only limited N fertilization was used. No special equipment would be needed for production. Kochia was the highest yielding species in the most arid region and could be produced on some of the cheapest land. However, there is much we do not know about kochia production like optimum fertilization, consistent seed germination (1991), seed production, allelopathic effects, volunteer plants, etc. The only apparent disadvantages of kochia as a biomass species seems to be the relative high ash and N concentrations, and its weedy nature. We conclude that additional research should be funded to further evaluate kochia as a biomass crop for the northern Great Plains.

Biomass cropping on fallowed land utilizing a leguminous biomass species was successfully evaluated in 1990-91 only due to stand failures in two other years. We still believe the concept has merit, but more effective establishment techniques like no-till would need to be incorporated into the system.

Biomass yields of kochia dropped precipitously by delaying harvest until after a killing frost from loss of seed and leaf. Therefore, kochia must be harvested prior to frost to prevent yield loss. It may also be necessary to harvest earlier to reduce seed loss to prevent it from becoming a weed problem in subsequent crops.

Stand maintenance at high N fertilization levels should not be a problem in the northern Great Plains. Nitrogen fertilization of brome grass at 294 kg ha^{-1} for 38 years at Fargo has resulted in only slight stand deterioration compared with an unfertilized treatment. Little deterioration of perennial stands occurred in these experiments.

Herbaceous biomass can be economically produced in the northern Great Plains. If herbaceous biomass has a future in the energy picture of the United States, the northern Great Plains should be considered as a low-cost producer.

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