PROJECT TITLE: Develop a field grid system for yield mapping and machine control

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PROJECT AIM: To further develop Field Grid Sense and to demonstrate its suitability for field production applications.

TECHNICAL OBJECTIVES: Build and test the Field Grid Sense system for yield mapping and machine control during harvesting. Secondly, use Field Grid Sense with chemical application equipment to demonstrate a workable in-field system.

More specifically, the operation of the patented hardware/software Field Grid Sense (FGS) system will be tested in crop harvesting to demonstrate the system's utility and to analyze the flexibility of operation under true field conditions. Additionally, FGS will again be used with chemical application equipment - equipment that needs modification to correct one or two slight shortcomings. This action will create improved systems and establish the worthiness, efficiency and necessity of chemical application equipment that is controlled and directed via the FGS package.

DISCLAIMER

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Task 1: Expand the preliminary design:

Originally FGS was used with granular chemical application equipment. A primary utility of FGS is its use with each and every phase of crop production cycles. FGS will be adapted to the harvesting phase which will require buying and then modifying crop-harvesting equipment; assembling moisture content, volume and distance sensors on a combine; and arranging the FGS package in situ on the harvesting implement.

1. Buy David Manufacturing Incorporated moisture content sensors, Lucas inclinometers, Magnavox radar distance detectors, Hall-effect sensors with fifth wheel assembly, etc. and interface components and assemble the benchtop arrangement.

2. Bench test the system and analyze the correctness of the design specifications.

STEPS OF PROGRESS FOR TASK 1:

ls1. Mr. Rod Fischer was hired as a research associate/research assistant. Mr. Stan Nielsen was hired as a research assistant and is also assisting in the areas of software and hardware system development. Rod is perfecting the sprayer manifold and employing FGS with data analysis. Stan employed Kriekging software for data smoothing and analysis plus providing a more useable operation package.

ls2. An electronic harness has been assembled. This is a remake of a previous setup plus we've added workable and available components from our departmental R & D shops. Specific sensors have been selected. Overall electronic configuration have been developed and assembled.

ls3. The combine has been specified; specifications were written and the request was forwarded in the state bid process. The combine was purchased as of 3/15/93.

ls4. Several field tests were previously performed, as described under steps 2s1, 2s2 and 2s3. Also, the software and hardware plus overall system capabilities of FGS are continuously being improved. The field tests done on borrowed equipment plus our joined efforts with Agriculture Information Technologies of Iroquois, SD have been of great benefits. The improved FGS components will continue to be bench tested and used on the purchased combine to effectively and efficiently perform field tests.

ls5. The total combine-FGS assembly is developed, and has been placed on the combine.

ls6. This task is complete.
Task 2: Use FGS on the harvesting unit under field conditions

1. Prepare the field harvester with the FGS readout and sensory attachments.
2. Make field runs in University plots, on ARS farms and in producers' fields and observe the system workability; demonstrate system feasibility. Data will be collected from automated field measurements. Collected yield data will include bushels per acre, grain moisture content, grain temperature, field slope measurements, field position, field entered. The collected information will be shown graphically in a software derived fieldmap.
3. Refine the setup and make any necessary adjustments.

Steps of Progress for Task 2:

2s1. Great progress has been made toward this task. A combine has been purchased (we've spent considerable time and have purchased the needed one); plus, we were fortunate enough to be able to use a Plant Science harvester. The electronic components with computer and FGS were placed on the machines. Further system development took place; we've added program commands.

2s2. A working arrangement was put in place that allowed us to test the FGS/harvester system. Two sites were used at the USDA/ARS farm which is located directly north of Brookings, SD.

2s3. The results of both wheat harvest and corn harvest using the system were reported - it was determined that the system offers advantages over today's farming techniques. Maps and databases of yield, grain moisture and topography were produced which could be utilized in site specific crop management toward savings of inputs. These results were presented at two separate meetings (papers filed with previous report) -
   a) the SAE International Off-Highway & Powerplant Congress & Exposition in Milwaukee, WI
   b) the ASAE Winter Meeting in Nashville, TN

2s4. FGS was used on the combine as a joint project with Agriculture Information Technologies for harvesting grain during 1993 and is being used in 1994.
   a) The combine-FGS package was used on the SDSU/Dakota Lakes Research Unit at Pierre, SD on 9/30/93 thru 10/20/93. A profile of field data is attached.
   b) The combine-FGS package was used on Agriculture Information Technologies research unit at Iroquois, SD.

For both studies, GPS monitoring along with yield and moisture were recorded and post processed with soil and nutrient data maps. Also, at both sites comparisons will be made between yield monitor types. This info is being analyzed and summarized. Presentations were made in March.
Presented Results:

Following the pioneering work and methodology of Linsley and Bauer (1929), two 80 acre fields in central South Dakota were site specific farmed. The fields were first grided on a 200 ft by 200 ft grid, using a differential Global Positioning Satellite Receiver. Soil samples were collected (~15 subsamples within 20 ft. of grid center) and analyzed using accepted commercial soil testing analysis procedures. Geostatistical analysis was accomplished to develop iso-antecedent Nitrogen, Phosphorous and Potassium maps of the field. Only nitrogen was studied and varied in this experiment. The field was then grided into 270 ft by 270 ft field cells. These cells were fertilized with nitrogen in three different ways. A third of these cells were fertilized conventionally (100 lb/acre). The middle third were fertilized to develop yield response curves (0, 50, 100, 150 and 200 lb/acre). The last third of the plots were fertilized site specifically (yield goal 100 bu/acre) with the soil test antecedent nitrogen from the iso-maps subtracted from the recommended nitrogen amount to result in a fertilizer recommendation. Results of this study will be discussed in the poster.

2s5. The grant timeline has been extended to 11/95. Task #2 has being extended, where the harvesting system was scheduled for the 1994 harvest season. Updated hardware and software were included and tested. Results have been reported.

2s6. This task is complete.

Task 3: Modify present chemical application equipment to more properly dispense chemicals used in farm productivity. FGS has already been moderately successfully employed with chemical application equipment, however, present equipment has a major shortcoming in manifold design. The task is to modify the sprayer manifold, employ FGS and to demonstrate a workable system.

1. Buy sprayer and manifold, modify and assemble.
2. Assemble sprayer system with FGS package.
3. Benchtop test sprayer and prepare field system.

STEPS OF PROGRESS FOR TASK 3:

3s1. The design of a sprayer with a modified manifold has been completed. Components were specified. Mr. Rod Fischer has spent considerable time toward completing the assembly of chemical application equipment.

3s2. The sprayer system is field ready - the sprayer was used in chemical application during the spring and summer on both the ARS farm and the SDSU Agronomy lands.
3s3. The sprayer manifold and necessary system components have been connected to FGS and bench testing is continuing, plus field testing has taken place. Results were presented in March.

3s4. This task is complete.

Task 4: Test and demonstrate FGS with modified chemical application equipment.

4s1. Coordination continually occurs with the Plant Science Department and Agronomy Farms for selecting times, designating fields and locations, arranging for chemicals and laying out system operation to test and demonstrate FGS with the modified chemical application equipment. Actual field use occurred in April and May of 1993.

4s2. The sprayer, equipped with the modified manifold, was used in October on the SDSU Agronomy research units for liquid application. Results for fall tests were presented at the 2nd International Conference on Site-Specific Management for Agricultural Systems, March 28-30, 1994 in the Twin Cities.

Results:

With farm implementation of GPS Technology chemical spray rates will be varied to meet the requirements of a specific field position. This technology along with on-the-go spot spraying is replacing the common practice of applying a spray mix to a field at an average rate. Instead the spray application rate is changed on-the-go with the use of direct injection chemical units. Direct injection units hold the chemical concentrate in a factory supplied container. The carrier (water) is held in a second container. This allows the applicator to spray with minimum exposure to the chemical. When the operator is finished with a field any remaining concentrate can be returned to the manufacturer. This is a more environmentally sound practice than mixing a chemical solution with water in a single tank and having the potential for leftover spray mixture.

A significant concern when implementing this technology is the lapse time that results from the distance that the concentrate must travel from its source to the sprayer nozzles. Consequently, when the chemical injection rate changes, chemical application rates will lag by the above mentioned time offset. The poster illustrates a method to minimize the lag time error associated with a singular applied chemical (one injection system with water as the carrier). A change in the manifold system was made that enables a direct injection system to be used with reduced lag time. The system utilizes a small holding tank and uses limit switches for refilling.
4s3. Results for sprayer testing were presented at the 1994 ASME Region VII Technical Conference under the title of 'An Engineering System to Vary Flow Rate and Limit Machine Lapse Time'.

4s4. System results were presented by Mr. John Oolman at the ION GPS-94 Student Paper Competition in Austin, Texas during August, 1994.

4s5. This task is complete.

Task 5: Prepare final report:

5s1. Information is being gathered and compiled to go toward the final report.

ADDITIONAL ITEMS OF EFFORT AND PROGRESS:

A. A support arrangement involving system trials, use of equipment and a sharing of technology has been put in place. This is a great opportunity to test and demonstrate FGS in conjunction with a nationally-based company involved in crop production at the producer's level (a key company location is at Iroquois, SD approximately 55 miles from Brookings). A grant has been approved with the South Dakota Governor's Office of Economic Development via the Center for Innovation, Technology and Entrepreneurship and Ag Info Tech of Iroquois, SD.

B. An abstract had been forwarded to present FGS at the 'Biostress Symposia' for April-May, 1993. Presentation was made on May 24th.

C. A new member joined our research team. Dr. Dan Humburg of the Agricultural Engineering Department of South Dakota State University has been doing research in the area of machine design and machine vision. He'll put this expertise toward possible sensory and system employment utilizing FGS and information transfer and equipment control.

D. An article was prepared for the "IMPULSE" explaining the details and progress of the project. The "IMPULSE" is an informational journal of the SDSU College of Engineering with the next issue being published late summer.

E. Mr. Jack Aellen visited our site on 7/8 - 7/9/93. The visit was an opportunity to exchange significant information plus Mr. Aellen has continued to forward additional, quite beneficial information.

F. Ag Info Tech and SDSU researchers, as a team, have forwarded a grant proposal to the Small Business Initiative Research fund.
G. Further discussion on our research, system and findings are occurring with commercial assemblers and distributors in both Sioux Falls, SD and Minneapolis, MN.

H. Mr. Joe Schumacher attended the North Central Research Committee on Site Specific Farming under the CSRS/USDA Cooperative States Research Service/Dec. 2-4, 1993 in Kalamazoo, MI.
   * discussion on yield monitors
   * GPS receivers and accuracy
   * technology advances
   * environmental issues and equipment design
   * soil management and crop efficiencies
   * exchange of state reports
   (A summary of this meeting was published by the journal of 'Farm Industry News').

I. Abstracts and presentations were delivered at the 2nd International Management for Agricultural Systems on March 28-30, 1994 in Minneapolis, MN with the University of Minnesota.

J. Presentation and discussion of project and related technologies occurred during the 43rd Annual Soil and Moisture Clinic with SD Association of SCS and SDSU in November, 1993.

K. Presentation on the project was given at the 1st Annual Biostress Poster Session on 3/11/94.

L. Mr. Joe Schumacher, Mr. John Oolman and Dr. Dan Humburg attended the SDSU/University of Nebraska "Geostatistics" workshop during May, 1994.

M. Details of our project were released to the general public/media by Dr. Gregg Carlson of the SDSU Plant Science Department with articles in the Sioux Falls Argus Leader and the Brookings Register.

N. Details and outcome statements were released with the "South Dakota Farm & Home AES Research: within an article entitled: "Global Positioning Satellites: Signals from space to the field".

O. Mr. Tim Aughenbaugh of Ag Info Tech, Iroquois, SD our commercial partner presented details and system specs at the Lake Area Tech/BASF Demo Center, Watertown, SD on August 24, 1994.

P. A second CITE grant entitled "AIT Site Specific Solutions for Economic Productivity" has been prepared, undergone on-campus review and has been forwarded. The identified amount is $77,095.

Q. System results were presented at the South Dakota Irrigators Conference via the SDSU Cooperative Extensive Service and the SD Irrigators Association on December 6 and 7 in Mitchell, SD.
R. System and field results were presented by Mr. Joe Schumacher with a presentation entitled "Site Specific Farming in the 21st Century" at the 44th Annual Soil and Moisture Clinic at Brookings, SD on November 13-15, 1994.

S. The use and continual expansion of this technology was further explained within an article entitled 'Going High-Tech On The Farm', South Dakota High Liner Magazine, Feb. 95 Issue. Mr. Tim Aughenbaugh of AIT, Iroquois, SD, our commercial partner was featured.

T. Field Grid Sense was demonstrated and displayed at the South Dakota Space Day on April 6, 1995 in Pierre, SD (see Attachment A).

U. Information and methodologies involving precision farming and 'Field Grid Sense' techniques have gained tremendous interest. Systems are in use. Results and discussions on the subject were presented in several settings:

- 'Conference to examine new space-age farming' in the "Green Sheet" publication, Aberdeen, SD (see Attachment A).
- 'Farming the 21st Century', Conference: SDSU/Biostress (see Attachment B).
- 'Farming from the Sky', article: Brooking Register (see Attachment C).
- "GPS Promises Profit While Easing Environmental Concerns', article: The Farmer/Dakota Farmer, August, 1995 (see Attachment D).
Joe Schumacher, research associate at SDSU, describes global positioning system (GPS) and yield monitoring equipment is use on a combine at the Dakota Lakes Research Farm near Pierre. The cooler insulates a computer and receiver from the heat. The rooftop antenna is used to receive satellite signals. Experts will gather in Brookings, Monday, August 14 to explore precision farming with producers, this combine will be part of the evening, hands-on evaluation session.

Conference to examine new space-age farming

BROOKINGS — With the 21st Century only four and a half years away, a whole battery of space-age technology is lining up to make its mark in a new century of farming.

Precision farming, the practice of managing fields by the square yard, will be the topic of a producer-oriented conference Monday, Aug. 14, on the campus of South Dakota State University.

The conference runs from 9 a.m. to 7 p.m. in the Northern Plains Biostress Lab. Registration is $20 at the door. Register with Verna Mae Van Maanen, Plant Science Department, SDSU, Brookings, S.D. 57007, telephone (605) 688-4600.

Nearly 20 experts — from SDSU, USDA, University of Minnesota, and private industry — are on the program to tell how

(See PROFITS, Page 2)
Profits: Real potential through intense management

(Continued from Page 1) they foresee precision farming affecting their areas of expertise. Those areas include weeds, insects, diseases, fertility, machinery, and many other areas.

“Precision farming offers real promise to farmers who wish to improve their profits through more intense management of their land,” according to Gregg Carlson, professor of Plant Science, and Extension water quality specialist at SDSU.

Carlson is coordinator of this conference along with John Oolman, David Clay, Dan Humberg, and Joe Schumacher. For the last three years, they and others have been using the Global Positioning System and evaluating the implication of precision farming in South Dakota.

In layman’s terms, they are attempting to adapt the same technology that U.S. armed forces used for pinpoint bombing of targets in Iraq during the Gulf War for “pinpoint fertilizing, weed control, insect control,” and so forth.

Pulling together this array of speakers into one conference is just part of that effort.

Morning speakers include:

Paul Fixen, Potash and Phosphate Institute, Brookings, with an overview of precision farming. Gary Lemme, superintendent, West Central Experiment Station, University of Minnesota — Morris, on landscape variability. Dwayne Beck, manager of Dakota Lakes Research Farm, Pierre, on how precision farming fits into farming systems.

Promises: Corn, soybean, wheat are in tight supply

(Continued from Page 1) This is “lock-up” at USDA, the final step in the making of the August Crop Report. Although USDA releases hundreds of crop and livestock production estimates throughout the year, none are more nervously anticipated than the August crop estimates — the first peek at the year’s potential harvest.

But this year’s peek promises to be an eye-opener. Corn, soybean and wheat supplies are historically tight and grain prices are coiled to explode upwards — as are food prices — if the August report confirms the late, wet spring and early, hot summer has clipped potential production.

Like everyone else, however, no one at USDA possesses more than a guess until the lock-up process begins. After the doors are sealed, a security specialist retrieves — from a vault — crop estimates already gathered from selected states around the U.S. This on.

Sharon Clay, weeds researcher, SDSU, on spatial weed populations. Michael Ellsbury, Northern Plant Insect Research Laboratory, USDA, on spatial insect populations. Jim Doolittle, SDSU Plant Science researcher, on the new statistics, and what geostatistics mean to a farmer and why maps can look like “bogus bologna.” Roy Scott, soybean breeder, SDSU, on plant response to a variable environment. Noon luncheon speaker will be Grant Mangold, editor of Ag Innovator Newsletter of Successful Farming, talking on agricultural innovation.

Gregg Carlson, SDSU, will kick off the afternoon program, discussing transition to quantification. Afternoon program will consist of a panel discussion on machinery, moderated by Dan Humberg, assistant professor of ag engineering, SDSU. Panelists follow:


A hands-on demonstration of machinery is planned for the evening.

It’s hot it’s tin

You can tell it’s hunting season. Going around the looking over discussion which be best for deer. Funny what memories.

One November friends and I go about deer hunting standing in the aboard US Th (CVN-71), a story in perspective, must realize the about life at sea. People, you must people.

So, there we patiently for our and beef yakis some young air. Michigan pipped.

"Man, if I was, I’d be getting ready hunting pretty ain’t."

Just pick up

When I asked him he used to he looked stunned.

"A 30/30," he respondantly. "That’s all of gun there is going. It’s light. It handles like a car and gets 100 yards."

Eyes rolled a down the show shuffling ahead plugged USDA's newly minted crop estimates from Texas was notes that is issued simultaneously with the August to
Farming the 21st Century

Precision Agronomics

A producer oriented precision farming conference

14 August, 1995

Room 103

Northern Plains Biostress Building

On the Campus of South Dakota State University
Brookings, South Dakota

Sponsored by

South Dakota State University
South Dakota State University Agricultural Experimentation Station
South Dakota State University Cooperative Extension Service
Professional Soil Scientists Association of South Dakota
South Dakota Water Resources Institute (USGS - 104 Program)
USDA - CSRS Management System Evaluation Area (MESA)
USDA - ARS Northern Grain Insect Laboratory
The Big Sioux Aquifer Demonstration Project

Conference Committee:

Dr. Gregg Carlson
Dr. David Clay
Mr. John Oolman
Dr. Dan Humbug
Mr. Joe Schumacher

Attachment B
Farming the 21st Century

Precision Agronomics
A producer oriented precision farming conference, 14 August, 1995
Room 103
Northern Plains Biostress Building
On the Campus of South Dakota State University
Brookings, South Dakota

Conference Committee: Dr. Gregg Carlson, Dr. David Clay, Mr. John Coitman, Dr. Dan Humburg, and Mr. Joe Schumacher

09:00-0910 am. Welcome to South Dakota State University and the Precision Agronomics Conference
Dr. David Bryant, Dean of College of Agriculture and Biological Sciences

09:10-09:35 am. An overview of Precision Farming.
Dr. Paul Fixen, Potash and Phosphate Institute, Brookings South Dakota

09:35-09:55 am. Landscape variability. Why You May Decide to Precision Farm!
Dr. Gary Leme, University of Minnesota, Morris Minnesota

Dr. Dwayne Beck, Manager Dakota Lakes Research Farm

10:25-10:40 am. Coffee Break

10:40-10:55 am. Spatial Weed Populations. Why You May Decide to Precision Farm!
Dr. Sharon Clay, South Dakota State University

10:55-11:10 am. Spatial insect populations. Why You May Decide to Precision Farm!
Dr. Michael Ellsbury, United States Department of Agriculture, Northern Grain Insect Laboratory

Dr. Jim Doolittle, South Dakota State University

11:25-12:00 am. Plant Response to a Variable Environment. Why You May Decide to Precision Farm!
Dr. Jackie Rudd, South Dakota State University

12:00-01:30 pm. Noon Luncheon, Volstorff Ballroom, University Student Union
Noon Luncheon. Volstorff Ballroom, University Student Union

12:00-01:30 pm. The Transition to Quantification.
Dr. C. Gregg Carlson, South Dakota State University

01:30-01:45 pm. The Transition to Quantification.
Dr. C. Gregg Carlson, South Dakota State University

01:45-05:00 pm Machinery Panel and Discussion. Dr. Dan Humburg, South Dakota State University

01:45-02:15 pm. Global Positioning Satellite Technology and it’s Use in Agriculture.
Dr. Dan Humburg and Dr. Noel Anderson, Concord, Inc.

02:15-02:45 pm. Yield Monitoring.
Mr. Chris Foster, John Deere, Inc.

02:45-03:00 pm. Coffee Break

03:00-03:20 pm. Using Remotely Sensed information.
Dr. Dennis Helder, South Dakota State University

03:20-03:50 pm. Variable Rate Fertilization.
Dr. Nyle Wollenhaupt, Soil Teq, Inc.

03:50-04:05 pm. Variable Rate Seeding.
Dr. Noel Anderson

04:05-04:20 pm. Sprayer Injection Systems.
Mr. Dave Reid, Raven Industries, Inc.

04:20 -04:50 pm. Mapping and Information Management.
Mr. John Soderholm, RDI Technology, Inc.

05:00 -07:00 pm. Machinery and Software Demonstrations

Registration For Conference is $15 by Aug. 10, 1995 or $20 at the door. Register in advance with Verna Mae Van Maanen, Plant Science Dept., South Dakota State University. Phone Number (605)-688-4600.
Registration includes the Noon meal, Coffee Breaks, and handouts.
Welcome and an introduction to  
Farming the 21st Century  
Precision Agronomics

Shortly after our forefathers started cultivating the land, they recognized that there were (and still are) inherent differences in the agronomic production potential of different fields or parts of fields. Different parts of a field exhibit unique response to different soil amendments, and plant varieties. These differences led to the development and adaption of management practices uniquely suited to specific portions of a field. To mention just a few, during the drought years, lowlands were planted to high water use crops such as corn while uplands and coarse textured soils were planted to low water use crops such as small grains. When seeding small grain with a horse drawn endgate seeder, plant populations were changed on the go. By regulating the seed discharge opening. Higher populations were planted to the more productive soils and lower populations were planted into the poorer soils. In the central cornbelt (Illinois and Indiana) unique soils in different parts of fields exhibited different pH levels. These different areas were site specifically treated with varying rates of ground limestone. Manure was selectively applied to eroded and less productive sidehills.

From the early 1950's to today farm size has grown. During the horse drawn farming years, normal cultivated row crop acres farmed by an individual farmer, seldom exceeded 40 to 80 acres. Today it is not unusual to find a single operator that farms in excess of 1000 acres of row crop production. When farming only 40 acres, it was possible to site specifically manage 2 or 3 acre plots. When farming 1000 acres or more, the modern farmer that tries to manage different individual parts of fields (2 or 3 acres) experiences an information overload. However, modern farmers are keenly aware of the significant agronomic differences that exist across most fields.

Scientists across the world have concluded that we have left (or are in the process of leaving) the "Industrial Age" and are entering the "Information Age".

For farmers, the reality of entering the "Information Age" will be a traumatic change in management philosophy. A farmer that now manages fields, will soon (once again) manage small land parcels within the field, without experiencing the "information overload" mentioned above. Two significant technological advances are responsible for this change. They are the miniaturization and reduction in cost of high speed digital computing equipment and the universal access to a accurate geographical positioning system.

With this new technology the farmer's onboard computer will be able to know where in the field it is at any time. The onboard computer will have the capability of archiving data from multiple different information gathering devices and this data will be
available for almost instantaneous recall. The archived data will be an integral part of the farmer's decision making process. The onboard computer will also have the capability of precisely controlling the rate of application of agronomic inputs (fertilizer, seed populations, seed varieties and or pesticide) onto/into a precise location within a field.

The goal of engineers developing precision farming machinery is to make the technology as transparent to the operator as is possible. The only exception to this transparency, will be the farmers increased management responsibility. Instead of making a management decision for a field, he will now have to make a range of management decisions for many parts of that field. It is the goal of this conference to discuss how we will accomplish this intense farm management as we enter the 21st century.

11 August, 1995
Precision Agriculture

Paul E. Fixen
Northcentral Director
Potash & Phosphate Institute

A revolution is taking place in agriculture. It redefines the basic production unit from the area between fencelines or roads to a much smaller more homogeneous unit. It’s a revolution enabled by machines, satellites, and computers but based on the power of information.

Is it really a revolution or is it nothing more that a passing fad that has captured the attention of techno-maniacs? Growth rate statistics indicate that it is for real. Approximately 200 fertilizer applicators capable of varying rate and blend on the go are in use today with 70 to 90 being added annually. They covered about 1.3 million acres for the 1995 crop, a portion of which will be harvested by 4000 to 5000 yield monitor equipped combines currently owned by North American farmers. Nearly 3000 of those monitors were sold in 1995 alone. Purdue University estimates that 7500 farmers are currently using at least one precision technique. Conferences featuring precision technology and information management this summer organized by the Potash & Phosphate Institute have drawn diverse audiences numbering around 800 each. Nearly every Land Grant University in the country has one or more research or extension projects on some aspect of precision agriculture. If this is a fad, a tremendous number of people have been fooled.

The stimulus for much of the interest in precision technologies has been recognition that significant additional gains in crop production efficiency will be very difficult without managing for within-field variability of soils, soil test levels, and yield potentials. The degree of variability measured has surprised even the experts. One extensive survey of grid-sampled fields in the Red River Valley showed typical soil nitrate levels ranging from 30 to over 150 or even 200 pounds per acre two feet. An evaluation of nearly 400 grid-sampled fields in southern Minnesota showed that 86% of the fields sample had 4 or 5 soil test P classes present (VL, L, M, H, or VH). Yield monitors have revealed that yields frequently vary at least 100% across the field. Variability appears to be the norm, not the exception.

No single protocol for measuring soil variability will likely surface. Grid-sampling is undoubtedly part of the process throughout the corn belt where a long history of fertilization, manuring, and crop removal exists. In some cases the scale of variability is such that soil property sensors may be necessary to fully account for existing variability. On the other extreme, preliminary investigations in the Great Plains indicate that sampling by landscape position or based on a topography map may be adequate and make precision technologies affordable for low cash-flow crop rotations.

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The information being generated by yield monitors coupled with other site specific data relating to the myriad of factors that influence crop yield and quality is quickly becoming a national treasure. Fully tapping the power of that information is no small challenge and will involve sophisticated data base management tools, intellectual property rights issues, and data pedigree issues. Currently growers are using yield monitor output to develop an archive for future use, to verify the magnitude of obvious problems, to define appropriate questions, and in some cases to conduct strip trials designed to help answer those questions. The existence of extensive data bases will redefine the role of the agricultural scientist as these data bases become a major source of new information and knowledge. In the future, the agricultural scientist may be focused more on defining the protocols of how to answer agronomic questions on the farm than on answering the questions themselves.

The economics of precision technology are in constant flux as the technology changes and more knowledge is gathered on appropriate use. The most relevant question to ask is not whether precision technology is profitable, but rather, at what level of variability does it become profitable. Clearly precision approaches would have nothing to offer to the bottom line of that mythical “uniform field”. At the other extreme, if soil testing has any validity what-so-ever, good economies must result from recognizing that a field area testing very low in a nutrient should be managed differently from one testing 3 times what it takes to be classed as very high. Somewhere between the extremes exists a current economic break-even point. The profitability of yield monitors is very difficult to access since much of its economic impact will result from the long-term data base it helps generate. Intuitively it appears to be an investment that will provide an excellent return.

Precision agriculture will continue to change at a rapid rate due to growth in knowledge and advances in technology. Fierce competition within industry will continue to drive advances at the same time strategic partnering and alliances will bring together the diverse skills needed to refine and support this complex management approach.

Has true “precision agriculture” arrived? No, but we have turned the corner and that turning has brought the target into sight. Some form of precision agriculture will become the conventional agriculture of the future as economic, environmental, and productivity demands guide us to greater and greater precision.

Landscape Variability: Why You May Decide to Precision Farm
Precision Agronomics Conference; SDSU, 8-14-95

Gary Lemme, WCES Head/Professor &
Acting Assistant MN Ag. Exp. Station Director, University of Minnesota
contributions by G. Johnson, P. Roberts and G. Rehm, University of Minnesota

Precision agriculture is a management philosophy that is information and technology based which allows resource managers to identify, analyze and manage site/soil spatial and temporal variability with the goal of enhanced agricultural sustainability (profitability, environmental sensitivity and community building). Variable management of a field to obtain optimum profitability while enhancing the soil and water resources of the area assumes that the decision making process that led to these actions was based upon data, knowledge, and wisdom.

Precision farming requires an understanding of the effects of natural and human induced soil variability upon crop yields and the natural resources of a field. Soils are the result of the interaction of the five soil forming factors: parent material, climate, time, topography and vegetation. Natural differences in soil properties within a field are generally the result of variation in topography and parent material. Past farming practices, such as manuring or the consequences of past practices, such as erosion, will have altered the natural variability pattern of soil properties.

The data requirements to implement precision farming exceed that of conventional farming. Global positioning technology permits accurate location of soil sampling information. When combined with computer mapping software, these data can be graphically displayed in the format of user friendly maps. Soil sampling intensities for precision farming greatly exceed that of uniform farming approaches. These data should document not only nutrient status but also soil physical properties such as drainage, water holding capacity and permeability.

Geographic information systems permit layers of spatial information to be combined to assist farmers in making decisions on where and at what magnitude management will be varied across a field. The utility of the information will increase as information is gathered over time. Financial returns to precision farming will vary with the amount and type of variation found in a field and the net value of the crop produced. Environmental benefits derived from adjusted application rates are difficult to quantify but are equally important. In fact, environmental benefits may be more important in today’s regulatory oriented world.

Precision farming is a management philosophy that should be considered by large and small farmers. Certain aspects of the process, such as information recording and management, will be beneficial to nearly all producers. Other producers will feel comfortable and realize benefits from the adoption of the entire process. Universities should work in concert with farmers, agribusiness firms, and each other on a regional basis to provide timely and need based information to assist producers in assessing these technologies.
Site Specific Weed Management
Fact or Fiction?

Dr. S.A. Clay

Prescription Farming - system of precise soil testing and field mapping to tailor inputs to individual areas of a field

Variable rate weed control - varying herbicide rate on-the-go, especially in nonuniform fields

Precision herbicide application - placing the herbicide(s) in the areas only where needed

Spot spraying usually implies a secondary or "touch-up" operation, where the others are would be the primary operation.

Blanket herbicide applications are efficient if:
   a. Weed species and populations are fairly homogeneous and above a level that reduces harvestable yield
   b. Weed populations are uniformly distributed
   c. Soil conditions are uniform (for pre-emergence applications)

How can site-specific management be used in weed management?

1. Preemergence herbicide applications
   a. Weed species and population variability to vary herbicide rate (some or none) and type
      Map areas having high weed populations at harvest the fall prior to herbicide application (most reliable) or through soil sampling of weed seed banks (?)
      b. Soil variability to vary herbicide rates
         Often labeled rates for preemergence herbicides vary with soil type and organic matter (examples Extrazine, Harness)
         Requirements:
            1. Accurate soil maps (obtained using soil survey maps, grid sampling, or other techniques) on which to base recommendations - Can be plotted using GIS (Geographical Information System) and field position determined by seat-of-the-pants or GPS (Global Positioning System)
            2. Control systems for sprayers that are accurate and reliable
               a) direct injection sprayers that change type, rate, and dilution of application; or
               b) variable rate on board herbicide impregnation equipment.
            3. Chemicals formulated for direct injection sprayers

2. Post-emergence herbicide application - because you can see the weed problems do not need to use GIS or GPS
   a. Use of sensors that "see" and/or ID weeds (green sensors,
infrared sensors, video imaging) Sprays only areas containing weeds by activating specific nozzles on the boom.

b. Define spatial variability of weed species and population after emergence by scouting (field scout, aerial photos?), use threshold levels to define area(s) of application (examples)

c. Variable rates (??) - may be used if weeds are small, environmental conditions for control optimal, prior history with reduced rates has been good

Advantages of Site Specific Weed Management

1. Saves money and herbicide by reducing application rates to some areas
2. Better weed control by putting on the correct amount
3. Minimizes environmental hazards
4. Only apply to areas where weeds are a problem
5. Cost of control may be much cheaper in one crop than another

Disadvantages

1. Risk of poor performance if rates not accurately varied
2. Company product liability????
3. Cost of equipment to apply the herbicide may not justify the expense ($1.50/a application vs $30/a application)

Unknowns

1. Stability of weed populations through a rotation ie. If allow weed escapes this year, do not how large a problem is created for next year
2. Sampling strategy to best estimate weed problems
3. Threshold levels for weeds and the environmental effects (less problem under irrigated than dryland conditions)

Questions??
Spatial Insect Populations — Why you may decide to precision farm.

M. M. Ellsbury

USDA—ARS, Northern Grain Insects Research Laboratory, Brookings, South Dakota 57006

The traditional approach to insect pest management usually involves sampling to characterize fluctuating insect populations over time. The goal of such sampling or scouting is usually to determine if and when control measures should be applied to maximize yields with the least expense. We know that insect populations also fluctuate spatially over the landscape. However, the concept of managing insect populations on a spatial basis is relatively new and has not yet found general application to insect pest management in a field crop setting. Three relatively recent technological advances have been increasingly applied to spatial characterization of insect populations with implications for pest management: (a) geographical information systems (GIS), (b) geostatistics, and (c) global positioning systems (GPS). A summary of applications of geostatistics and GIS to spatial insect populations may be found in Liebhold et al. (1993).

A GIS is a computer software system capable of collecting, storing, manipulating, and displaying data that is geographically referenced. GIS can be used to produce overlaid maps of data such as spatial insect population density, yield variability, and soil fertility. Thus there is the possibility of producing layered maps that graphically illustrate potential correlations and interactions among spatially referenced data for insect pest populations. To date, use of GIS for characterizing insect populations has been limited primarily to large-scale regional applications, especially for rangeland and forest pests.

Geostatistics is a branch of statistics that was developed by the mining industry to predict the location of ore bodies from samples taken on a grid basis. A basic underlying concept of geostatistics is the notion that samples taken closer together should be more similar than those taken farther apart. Variability among a large number of samples (minimum of 30 to 50 sample pairs) can be represented by a variogram (Figure 1.) The variogram plots variability, $\gamma(h)$, among all sample pairs separated by a given lag distance, $h$.

Variograms have three features that often relate to spatial variability of insect populations. The point along the vertical (y) axis at which the curve levels off is termed the sill,
and represents overall variability in the sampling scheme. The point where the curve meets the vertical axis is termed the nugget and may be considered as sampling error or as variability not detectable at the present minimum distance between samples. The range is the lag distance (along the x-axis) beyond which sample values are not correlated. The range may be thought of alternatively as the minimal distance between samples for adequate characterization of a spatial insect population.

Kriging is a geostatistical technique that allows estimation of values at unsampled points. Often insect populations cannot be sampled directly. In such cases, related factors, such as soil moisture, plant nutrient status, or soil type, that are known to affect the distribution of insect populations may be sampled as indicators of possible insect infestation. Thresholds for pest control decisions then may be established for the combined indicators and a technique known as indicator kriging may be used to predict the probability that the indicator(s) will exceed threshold values in a given area of a field. The probability threshold for treatment decision may be set at any desired probability value, say 80 or 90%, that the insect population will exceed an economic threshold.

The advent of GPS, originally developed for military applications, has provided an accurate and reproducible means for geographically referencing sample collection sites in a field crop situation. GPS systems integrated with handheld data logging systems provide a rapid and economical means of collecting grid sampled data for spatial analysis of insect populations by GIS and geostatistical methods. The utility of these advances are only beginning to be realized in a field crop setting where management units are on the order of 20 acres to quarter sections of crop land, in contrast to the large (> 1 square mile) regional scales involved in spatial insect pest populations in rangeland or forest settings.

Reference

I What is Geostatistics?
Geostatistics is a statistical tool which can be used to estimate the value of a soil property that varies in space at an unsampled location from sample data near that point. Success in using geostatistics over classical statistics depends on the degree of spatial structure or spatial dependancy of the property. Geostatistics will not provide a better estimate if sample data are spaced at a distance greater that the range of spatial dependance of the parameter measured.

II Estimations of Soil Properties:
General problem: you have measured some soil property (Z), such as pH, EC, total Cd, or extractable P₂O₅ content, at several locations and you want to use these data to predict the value of Z at locations where you have no measurements. The figure below illustrates the situation: The X's indicate sampling locations and “O” is the location for which you want to estimate the value of Z. The solid lines mark the boundaries of four different soil classifications.
a. One approach would be to take the arithmetic average of all sample points.
   - Rough estimate because it embodies variation from whole region.
   - All sample points have the same weight in the estimation (1/n, if n sample points).

b. To reduce variation, a second approach would be to take the arithmetic average of sample points which are in the same classification as location 0.
   - Each sample has one of two weights: 1/m if in the same class as location 0, or zero if in a different class (m is the number of samples in the same class as 0, n is the total number of samples).
   - The sample nearest 0 has no weight because it is in a different class; however, sample locations far away in the lower left corner have the same weight as those locations nearest 0 within the same class.
   - This would be a reasonable approach if the soil class boundaries marked abrupt changes (discontinuities), but they generally do not.

c. Within geostatistics there is a procedure called kriging. In its simplest terms a kriged estimate is still a linear sum of data, as in approach a and b, but the weights of each data point used in the estimate varies according to its position in relation to the unknown location and the other data points.
   - Kriging weights are not all equal and are derived from a variogram or a spatial covariance function.
   - Points closer to the unknown location have greater weights than points further away.
   - To avoid bias the sum of the kriging weights sum to 1
   - Ordinary kriging provides an unbiased estimate with a minimum and known variance.
   - Confidence limits for the estimate can be calculated from the variance.
### III Theoretical Kriging Example

![Diagram of a grid with points A to G and a point X]

<table>
<thead>
<tr>
<th>Obs.</th>
<th>Point</th>
<th>Kriging weight</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td><strong>Blocks of side</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1x1</td>
</tr>
<tr>
<td>A</td>
<td>0.0497</td>
<td>0.0515</td>
</tr>
<tr>
<td>B</td>
<td>0.0263</td>
<td>0.0282</td>
</tr>
<tr>
<td>C</td>
<td>0.1688</td>
<td>0.1672</td>
</tr>
<tr>
<td>D</td>
<td>0.1674</td>
<td>0.1659</td>
</tr>
<tr>
<td>E</td>
<td>0.0205</td>
<td>0.0220</td>
</tr>
<tr>
<td>F</td>
<td>0.2715</td>
<td>0.2711</td>
</tr>
<tr>
<td>G</td>
<td>0.2959</td>
<td>0.2941</td>
</tr>
</tbody>
</table>

| Kriging variance | 0.6578 | 0.3235 | 0.1363 | 0.0826 |
| Classical estimation variance | 1.0390 |

Adapted from Oliver and Webster, 1991

- Points near to X have larger weights than those further away.
- Points that are clustered carry less weight individually than lone points the same distance away from X in a different direction.
- A point fairly close to X can be screened by another that lies between it and X and so is down weighted.
The weights change as the size of the block increases: those near the center decrease while those further away increase.

Kriging variance decreases as the size of the block increases.

Classical estimation variance is almost twice the kriging variance.

Kriging estimation variance can be mapped similarly to estimation values to determine regions where more sampling is needed.

IV The Variogram

This is a function used to describe how a soil property varies over a surface. The function mathematically expresses the way in which the variance of a soil property changes as the distance and direction separating any two points varies. The variogram assumes that variance depends on only the separation between points and not on their absolute positions.

Example: equally spaced sample points along a transect

A ___ B ___ C ___ D ___ E ___ F ___ G ___ H ___ I

<table>
<thead>
<tr>
<th>Lag (distance)</th>
<th>Paired Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>AB, BC, CD, DE, EF, FG, GH, HI</td>
</tr>
<tr>
<td>2</td>
<td>AC, BD, CE, DF, EG, FH, GI</td>
</tr>
<tr>
<td>3</td>
<td>AD, BE, CF, DG, EH, FI</td>
</tr>
<tr>
<td>4</td>
<td>AE, BF, CG, DH, EI</td>
</tr>
<tr>
<td>5</td>
<td>AF, BG, CH, DI</td>
</tr>
<tr>
<td>6</td>
<td>AG, BH, CI</td>
</tr>
<tr>
<td>7</td>
<td>AH, BI</td>
</tr>
<tr>
<td>8</td>
<td>AI</td>
</tr>
</tbody>
</table>

The variance between each paired set of points is calculated and then plotted as a function of the lag or distance of separation.

Lag = distance between paired observations
Sill = plateau in variance (population variance)
Range = limit of spatial dependence
Nugget = random variation (analytical ??)

Must have sufficient data, minimum of 200 points.

Must use an “allowed” mathematical model to describe the main features of the variogram.
Interesting historical note: Researchers at Rothamsted found that plot-to-plot variance in crop yield decreased as plot size increased up to a limit. Beyond this limit, 0.01 ha, the variance stabilized (Mercer & Hall, 1911).

0.01 ha = 0.02 acre = 1,076 ft² = 20' X 54' strip = 538' grid

V Cokriging

- An intensively sampled soil property can be used to help improve the estimate of a sparsely sampled property if the two soil properties are spatially correlated.
- Some soil properties can be measured less expensively than others. If there is an analytically inexpensive soil property that is spatially correlated with an analytically expensive soil property, the inexpensive soil property can be used to estimate the expensive soil property. However, the estimate will be less precise.

VI Literature Cited
The Transition to Quantification

or

"When you can measure what you are speaking about and express it in numbers, you know something about it; But when you cannot measure it, when you cannot express it in numbers, your knowledge is of the meager, unsatisfactory kind."

Lord Kelvin, 1824-1907

by

C. G. Carlson and J. M. Oolman

Seeding Rates:

Site specific management allows one to evaluate the performance and manage the production of crops in small areas of a large field. A most difficult task is to determine the rate at which seed, fertilizer, and pesticides should be applied site specifically across a field.

To determine the site specific rate at which seed, fertilizer, and pesticides should be applied, we begin by looking at how these decisions are made on a field size basis today. First, the example of seeding rates, and plant population. Later we will discuss nutrient rate of application. The decision criteria for determining a plant population (or fertilizer rate) for a field is based upon the economics of yield response. Simply put, are you willing to trade your $0.50 of input for $1.00 of output (yield)? The answer to this question is obvious. What about your $2.00 input for $1.00 of output? Again the answer is obvious. There comes a point where trading takes place at values of $0.99 for $1.00 and $1.01 for $1.00. You would certainly take a trade of $0.99 input for $1.00 output but perhaps with less enthusiasm. At $1.01 for $1.00 you will chose not to trade. Your decision for each of the above mentioned potential trades was intuitive and obvious. To understand and obtain solutions to future problems, we will create a graphical representation of this transaction. This will help the transition into more complex analysis.

Note that on this graph, the 45 degree line distinguishes between a profitable trade and a nonprofitable trade.
A Farmer's decision making process used to determine the quantity of seed and fertilizer should parallel the above decision making process. It is true that if a farmer planted 1 corn seed per acre he would receive a return of perhaps 200 - 400 corn seeds. An obvious profit not considering fixed costs. If he would plant 2, 10, 100, or 1000 seeds per acre, he would continue to increase the fields profitability. However, if the farmer were to plant 400,000 corn seeds per acre, (figure a 80,000 seed bag at $80.00/bag which is $1.00/1000) he would probably have reduced grain yield. Certainly the return would not justify the $400.00 worth of seeds/acre. This obviously would not be profitable.

This discussion is the basis of a yield response curve. Yield is a function a number of input variables. Plant population or seed population is an important input parameter. We would start with one seed/acre and continue to increase the seeding rate up to some point, at which there is no increase in yield. Obviously somewhere between the start and stop points is the most profitable plant population. Where on the yield response curve should the farmer stop increasing the number of seeds planted per acre? Where is the point of maximum economic return? Where is the point that $1.00 worth of seed returns $1.00 worth of grain. Present research methods would have plots in a field planted to four or five different populations bracketing what is believed to be point of maximum economic return. Consider the example of planting corn into dryland conditions in Central South Dakota. The experimental rates of 15,000, 20,000, 25,000, 30,000 and 35,000 seeds per acre would be planted. A yield response curve is developed by plotting yield in bushel per acre against plant population. The yield has been typically obtained by using a plot combine or by hand harvesting. Data is converted to $/acre for both the yield (output) and seeds (input) by multiplying by $/bu and $/seed. The point of maximum economic return is obtained by determining the point at which $1.00 worth of grain yield was returned for $1.00 worth of seed. The place where this response occurs, is at the point where the yield response curve slopes at an angle of 45 degrees.
Increasing Dollars of Input

Dollars of Output

Typical Yield Response

Point of maximum economic return

angle = 45°

\[ \Delta x = \Delta y \]

This theory will be demonstrated on some actual field data. In the case of this next graph Berg, 1994 point of maximum economic return is slightly less than at $25/seed. Probably around 24,000 plants/acre.

We came to this conclusion (24,000 plants) in a similar manner as was accomplished earlier when generic inputs and outputs were traded. At populations of less than 24,000 plants per acre, there is a return of more than $1.00 for every dollar invested and at populations greater than 24,000 plants the return is less than $1.00 for every dollar invested. Further analysis should be accomplished to determine the potential loss from 1000 plants too much and 1000 plants to few. Commonly researchers will solve this type of problem in an analytical manner rather than using a graphical solution to the problem. Using regression analysis, an equation (a parabola, a parabolic spline, or a more
sophisticated equation) would be written that best describes the relationship between yield and plant population. This equation could be converted to: $\text{Syield/acre} = f(\text{Sseed/acre})$.

Using calculus, it would then be differentiated and set equal to 1 (the equation could be solved directly by setting it equal to the ratio of the cost of seed to the value of the grain). The equation is solved giving the point (the $\text{Sseed/acre}$) of maximum economic return. This is then converted to the most profitable population for the tested field. By looking at a number of studies such as the study above, over a number of years and a number of locations, a general recommendation for the most profitable population by location is obtained. The above work was usually conducted on the most productive homogenous parts of a selected field.

Most farmers and researchers agree that the plant population at the point of maximum economic return will be different for a deep, heavy lowland soil compared with a shallow, coarser eroded sidehill soil.

Most cultivated fields are not homogenous. Fields have both high yielding and low yielding areas within the field. Site Specific Management techniques give a farmer the potential to manage (change) the fields plant populations on the go. What is the population that gives the maximum economic return within each of the different portions of the field? To answer this question, we will continue to use the same line of economic reasoning for decision criteria that was developed above. We want to know what the point of maximum economic return is for every location in the field.

To begin, a definition of a new term, yield potential, is necessary. For this discussion, the yield potential of any point within a field is defined as the average yield over a number of years of a point in the field plus (or minus) a weather driven deviation term. The deviation term corrects for the inherent yield difference resulting from wet and dry years. The yield potentials over a number of years for a very large number of points (actually yield potentials are defined analytically by a series of polynomial equations that are continuous and continuous in their first derivatives at the block boundaries) in a field are defined as a function of spatial coordinates (latitude and longitude). To estimate the most profitable plant population at every point in the field, experiments are set up in the following manner. A field is normally planted to 25,000 plants per acre, the majority of the field is planted to this population. There will however also be complete rows planted to 15,000, 20,000, 30,000, and 35,000 plants per acre. These rows will always be sandwiched between a pair of 25,000 plants per acre rows. Preferably there will be 4 to 6 complete rows planted to each of these different populations relatively uniformly (Statisticians; forget the random thing. We used random locations as a statistical method for accounting for spatial differences. With Geostastics we now analytically account for these spatial differences.) spaced across the field. The entire field will be harvested with a GPS - Yield monitor - computer acquisition equipped combine. Data from these GPS and yield monitor devices will be stored by the computer acquisition system every second of the harvesting process. Using this yield data, cokriging, and sliding polynomials, maps (algebraic surfaces identical to the yield potential maps described above) for each
population at every location will be estimated. Using regression analysis, an equation will be generated defining yield as a function of yield potential and plant populations. (We have tried a number of different methods and are not certain which method is the most effective analysis procedure but the above seems to work. There is no doubt that our procedures will change with time).

As a first approximation we will fit the following (inappropriate but easy to use) equation:

\[ \text{yield} = a + b \times \text{pp} + c \times \text{pp}^2 + d \times \text{yield}_p + e \times \text{yield}_p^2 + f \times \text{pp} \times \text{yield}_p \]

\[ \text{yield} = \text{yield} \]

\[ \text{yield}_p = \text{yield potential} \text{ (we are using a long term average at a point in the field with the option to correct for a forecasted weather condition)} \]

\[ \text{pp} = \text{plant population} \]

Using this new equation, yield will be partially differentiated with respect to plant population and set equal to the ratio between the cost of seed to the value of the grain and solved across the full range of yield potentials. This will create an equation of plant population at the point of maximum economic return as a function of yield potential.

\[ \frac{\delta \text{yield}}{\delta \text{pp}} = b + 2c \times \text{pp} + f \times \text{yield}_p \]

\[ b + 2c \times \text{pp} + f \times \text{yield}_p = \text{cost of seed/value of grain} \]

so

\[ \text{pp} = \frac{\text{cost of seed/value of grain} - f \times \text{yield}_p - b}{2c} \]

A practical example of this procedure follows. Data was taken from work accomplished by Pioneer Seed Company. The following table was developed using data from 196 environments in 12 States and Ontario between 1978 and 1993. 10 to 15 hybrids were used. Carter, 1995. The yield potential was calculated from the average of different populations. This is not the ideal method (nor our recommended method) of determining yield potential but for this example it is functional.

<table>
<thead>
<tr>
<th>plant pop (1000)</th>
<th>yield potential (average of yields)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>84       114.25 122.75 150.25</td>
</tr>
<tr>
<td>18</td>
<td>86       109     125     139</td>
</tr>
<tr>
<td>22</td>
<td>84       114     132     149</td>
</tr>
<tr>
<td>26</td>
<td>84       118     135     155</td>
</tr>
<tr>
<td>30</td>
<td>82       116     135     158</td>
</tr>
</tbody>
</table>

Using regression analysis results in the following equation coefficients

\[ a = -3.357724566 \]
yld = a + b*pp + c*pp^2 + d*yld_p + e*yld_p^2 + f*pp*yld_p

δyld/δpp = b + 2c*pp + f*yld_p

If corn is worth $2.50 / bu and seed sells for $80/80,000 seeds or $1/1000 then the ratio of the cost of seed to the value of the grain = 1/2.5 = 0.4.

so b + 2c*pp + f*yld_p = .4
or pp = (0.4 - f*yld_p - b)/(2c)

to use this equation with your hand calculator for a 200 bu/acre yield goal, you would calculate as follows;
(0.4 - (.022738*200) - 2.5327) / (2*(-0.096354)) = 34.66 or 34,660 plants/acre.

If the yield potential yld_p were allowed to vary from say 40 to 200 bu/acre, the following represents a graphical solution to this equation. Note that the response is linear. This results from the equation used (actually we believe a nonlinear equation to be more theoretically correct). In the area of practical usefulness, (100 - 200 bu/acre) this equation is probably not too bad.

Most Profitable plant populations
plant population in 1000/acre

An actual field example will be of benefit to us. We have yield monitor data from an irrigated corn field in central South Dakota. The field averaged 181 bu/acre. Maximum recorded yield was 234 bu/acre and most yields were above 150 bu/acre. The next figure represents the probability distribution of yield for the field. Note that summation of all probabilities between 1 and 234 bu/acre (integration of the curve) results in 1.
The probability distribution of the fields' yield is one of the most important pieces of information that is obtainable from a yield monitor. With this information alone a significant amount of management is possible. As an example, if the curve showed that the majority of the field had yields from 180 to 190 bu/acre, there would be little economic benefit from precision farming.

A question frequently asked is, if a single population were planted to the entire field, how will the return per acre vary from a low planted population to a high planted population and how will return compare with site specific management of the field. It is clear that the answer to this question is dependent upon what seed costs and what corn is worth. In the following example it was assumed that seed corn costs $80/80,000 seed bag and that the market value of corn produced is $2.50/bu.. Note that the y axis of this next graph should be labeled "Return in dollars/acre". It is clear that the maximum return for the field in question occurs at plant populations between 32 and 34 thousand plants/acre. This is slightly above the population that would have been planted if the population were based upon an average yield of about 180 bu/acre. There are a number of assumptions used in this analysis that are suspect by the authors. We have inadequate time - space to discuss the details of these problems. However, it is safe to say that the results presented in this analysis are interesting.

**Return as a function of population**

($\text{corn} - \text{seed}$)
If plant populations were matched to the yield potential everywhere within the field in question (site specific precision planting), how would the return differ from the returns if a uniform plant population were used across the entire field? The following is a graphical representation of analysis of this question. The value of corn and cost of seed were the same as in the above analysis. Results of this analysis indicate that at a population of 32,000 plants per acre the difference is about $5.00/acre. At other populations, the difference is significantly greater.

**Difference between site specific farming and conventional farming**

![Graphical representation](image)

**Nutrient Management:**

The quantification of the response to nutrient additions (or antecedent nutrient availability) has been the subject of controversy for more than a century. In 1855 J. von Liebig introduced the "Law of the Minimum" which simply stated, says, that a plant's grain or mass production will uniformly increase in yield to the point that it runs out of a limiting nutrient. The "Classic Liebig" curve below is a visual representation of this concept. In 1909 the German scientist, E. A. Mitscherlich conducted a number of experiments and introduced the "Effect Law of the Growth Factors" which says that the yield of a plant will respond to increasing levels of nutrient availability in an exponential manner. The "Classic Mitscherlich" curve is also presented below.
As a farmer - production oriented person you are sitting back and saying "who really cares about the argument between two Germans that began almost a century ago". Before I answer that question, look at the curve below and decide for yourself which of the two curves best represents a graphical fit for a set of yield response data (*)

You conclude that the difference is trivial and that the exercise that you just completed was a waste of time. If you are in the business of making nitrogen fertilizer recommendations, the difference between your choice of curves, means a recommendation difference of about 10 to 40 lb/acre of nitrogen. Simply cynically put, if your are a fertilizer salesperson you believe in Mitscherlich and assume his analysis to be correct. If you are an environmentalist and greatly concerned with excessive agronomic nutrient application, you believe that Liebig was absolutely correct. Our purpose for discussing
this is to assure that it is understood that there is a profound difference in philosophy. In order to do a complete analysis of precision farming, we must agree upon an analytical representation of yield response. It is our objective to develop conclusions that are conservative (in the use of nutrient) in nature. For analysis purposes we have chosen to use the Liebig assumption of yield response as our basic assumption (as several people have noted, it is also easier to program). Actually there is a family of curves that represent yield response in a field and each curve is maximum at the highest yield potential for the location of concern. The following equation and family of curves represent those that were used in this analysis.

\[
\text{Nitrogen to be applied} = 1.2 \times \text{Yield potential} - \text{Nitrogen antecedent} - \text{Nitrogen credits}
\]

For a practical example we have chosen to use the same probability distribution curve that was shown earlier when discussing plant populations.

For the Central South Dakota irrigated field, the following is a curve that represents the dollar value difference between applying optimum fertilizer rates in a site specific manner and conventional field uniform fertilization practices. Additional assumptions are necessary to complete this analysis.

Assumptions
50% of the excess nitrogen applied is recoverable in the following year.
Corn is worth $2.50/bu
Nitrogen cost $.25/lb
This graph indicates that if a farmer had fertilized this field to a yield goal of 220 bu/acre, there would have been a savings of about $5.00/acre. Note that if the field had been fertilized to the field average of 180 bu/acre, the loss would have been close to $28.00/acre. It is obvious that over fertilization compensates for limited management. There are significant down sides to this discussion. Suppose the field in question is in a well head protection area and the farmer must pay for aquifer nitrate loading problems?

References

Berg, R. K. 1994. 34th Annual, Southeast South Dakota Experiment Farm, Beresford, Progress Report, Agricultural Experimentation Station, Brookings South Dakota

Farming from System leads to precise management

By Molly Miron
The Brookings Register

Farmers know their land varies from one end of a field to the other, but they can do better than managing crops, fertilizer and pest control by the seats of their pants.

The satellite technology of remote sensing has made farming a precision business.

During a seminar Monday, South Dakota State University scientists and experts from the United States Department of Agriculture, University of Minnesota and private industry explained various satellite systems that can bounce a signal from outer space to the inner space of a modem in a tractor cab.

About 150 farmers and crop consultants attended the conference.

Farmers can now gauge the correct management practices — almost to the square meter — using techniques such as those developed for pin-point bombing during Operation Desert Storm, experts told producers who gathered for the day-long event at the biostress laboratory on the SDSU campus.

"Precision farming offers real promise to farmers who wish to improve their profits through more intense management of their land," said Gregg Carlson, professor of plant science and Extension water quality specialist at SDSU.

For three years, Carlson, who coordinated the conference, and other researchers have been using the Global Positioning System, which has been applied to everything from rural addressing to soil surveys and warfare, to take the guess out of management practices.

GPS, Geographic Information Services, remote sensing, sophisticated guidance systems and computerized field machinery make site-specific farming possible, he said.

"It's developing technology," said Iroquois area farmer Tim Augenbaugh. "It's on-going. What we like about it is the data we're getting is usable in the future."

Aughenbaugh said he raises corn, wheat, sunflowers and soybeans on the large family farm. He farms with his brother, father, uncle and grandfather.

For the last four years, he said his family has used global positioning techniques for planning variable-rate seed and fertilizer applications and for monitoring yields. The object, he said, is to raise crops the most efficient way possible, reduce production costs and enhance income.

"We don't want to maximize our yield — we want to maximize our profit," he said.

David Bryant, dean of the SDSU College of Agriculture and Biological Sciences, compared sensing equipment and computers in the tractor cab to office and personal computer technology 15 years ago.

"In five years, precision farming will be more common, and in 13 years, half of all farmers will probably be using some of the technology," Bryant said.

A subscription to a satellite service costs about $600. John Crabtree of Farmers Implement on the U.S. Highway 14 Bypass said other equipment to get started in precision farming costs less than $10,000.

"That's peanuts compared to what the combine costs," Crabtree said.

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Agriculture from the sky

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Although the technology is geared more to large farms than those of one or two quarter sections, Crabtree said the site-specific systems should be environmentally responsible, rather than just economically feasible.

By charting each square yard of land, farmers can apply chemicals exactly where they are needed in the correct amounts.
GPS promises profit while easing environmental concerns

The same technology that enabled pinpoint bombing of Iraq by U.S. missiles and war planes during the Persian Gulf War is now being studied by South Dakota State University researchers for peaceful purposes.

The underlying motive of this research is to improve both groundwater and surface water quality. Site-specific farming promises greater profitability by increasing management intensity and reducing the negative environmental impact of agriculture.

How can it do that? Pesticides and fertilizers are routinely overapplied in many fields because we assume fields are uniform in soil characteristics. This overapplication hurts the environment. Meanwhile, we often underapply pesticides and fertilizers in other areas of the field. If we can tailor the applied nutrients to the needs of each plant in the field, we improve productivity while minimizing environmental impact. Both agriculture and society benefit.

SDSU’s research is occurring at Brookings and at the Dakota Lakes Research Station near Pierre. This is the third year we’ve had a yield monitor on a combine at the Dakota Lakes Farm. Operating the yield monitor with a Global Positioning Satellite (GPS) receiver has enabled us to record yield every second with its specific latitude and longitude. Such an equipped combine knows its location and the yield it is harvesting down to the second.

This data, recorded on a computer disk, can be taken back to the office computer and used to plot a yield map for the field. An accurate yield map has considerable potential for deciding where to fertilize, what fertilizer type to apply, and whether to increase or decrease plant populations. Such recommendations are made on a yield potential basis, rather than on a field yield-goal basis.

In Brookings, research is underway to test the accuracy of different kinds of GPS receivers. We are trying to develop a “probability of accuracy” curve, which would show the accuracy of each receiver. For example, the curve would show that one kind of receiver is apt to have a five-foot error, another has a 50-foot error, and so on.

One such accuracy curve shows a 200-foot accuracy can be improved to a 12-foot accuracy by switching to a “differential mode,” that involves use of a separate correction signal.

Aerial snapshots

We believe we will be able to appreciably improve the accuracy of site-specific farming by using aerial photography. First, we will use GPS to “learn where we are in a field,” and then transpose that information to an aerial photo in such a way that we know the latitude and longitude of every field point.

Excellent correlation results by matching GPS findings with aerial photo information. We can then accurately extrapolate field findings.

Based on what we know about equipment being manufactured and sold, we estimate the number of farmers using GPS technology in South Dakota now numbers in the lower hundreds. In five years, we expect 10 or 20 percent of farmers to be using GPS equipment. Crop consultants and grain elevators now express a tremendous interest and see potential for grid sampling of fields, a form of site-specific farming not tied to GPS.

Because of cost and economies of scale, GPS equipment will be more appealing to larger farms or those growing specialty crops with huge investments and great profit potential. At this time, we see the most application for corn-soybean growers in eastern South Dakota.

To illustrate economies of scale, if the equipment costs $3,000 and the farm size is 3,000 acres, the cost would be $1 per acre over the life of the equipment, or 20 cents an acre per year, assuming five-year equipment life. If the farm size is 300 acres, the cost is $10 per acre, or $2 per acre per year.

If the added profit through use of GPS technology is $5 per acre, the technology will pay off in both cases. The $5 estimate is ascertained by figuring that 20 lbs. less of nitrogen fertilizer will be used, or 2 more bu. per acre of corn will result.

Gregg Carlson is an extension water quality specialist at South Dakota State University and a graduate school professor.

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