![USGS]

WATER RESOURCES RESEARCH GRANT PROPOSAL

Title: Development of an On-the-Go Soil Sensor for Identifying Nutrient Management Zones and Improving Water Quality.

Focus categories: GW, MOD, NPP

Key words: Chemigation, Nitrogen, Phosphorus

Duration: Second year of three year study; May 1, 2000 to May 1, 2001

FY 2000 Federal funds: $15,000

FY 2000 Non-federal funds: $17,000 (Direct) $13,444 (Indirect)

Principal investigator's names and university: David E. Clay, Kevin Dalsted, Douglas D. Malo, and C.Gregg Carlson, South Dakota State University, Brookings, South Dakota.

Congressional district: First

Statement of critical regional or State water quality problems

To determine the agronomic barriers limiting the adoption of information technologies, several farmer workshops were held between 1997 and 1999 in Minnesota and South Dakota. These workshops identified the development of cost effective spatial sampling approaches as a top priority. This proposal is an outgrowth of those workshops.

Many rural South Dakota communities have been economically stressed by low crop prices, depopulated because of the efficiency of modern production agriculture, and have drinking water supplies contaminated by agrochemicals. Solutions to these and other agronomic problems can be solved through legislation or by developing creative approaches that solve problems. By targeting corrective management, site-specific management has the potential to simultaneously improve profitability and reduce the impacts of agriculture on the environment. Site-specific management may fill these need because it provides inputs in accordance with the specific needs of the crop, without providing excesses or deficiencies. In practice site-specific management applies the right management at the right time in the right way.

A critical component of precision farming is that it has the potential to reduce off-site transport of agrochemicals. A model developed by Stevenson (1986) shows why site-specific management farming can reduces off-site agrochemical transport. In Stevenson (1986) model, the relationship between N inputs to yield followed a logistic model, while the relationship between N inputs and lossed follows an exponential model (Stevenson, 1986). Due to the differences in the two models, under fertilized and appropriately fertilized areas contributed very little to nonpoint source pollution, while over fertilized areas contribute progressively more. Larson et al. (1997) tested this concept for N and showed that the largest advantage of site- specific management was during growing seasons where rainfall was above average. Similar relationships have been reported between P additions and P concentration in runoff water (Romkens and Nelson, 1974).

Statement of results or benefits

One of the first applications of site-specific management involved rigging a desktop computer to a fertilizer applicator for precise fertilizer applications. Today the emphasis has shifted from equipment to conducting system level experiments designed to develop conceptual understandings of complex interactions among weeds, crop genetics, soils, topography, water, insects, diseases, and nutrient cycling in watersheds. To accomplish this task, cost-effective sampling approaches for obtaining spatial information are needed. In the past, farmers and researchers have used grid sampling combined with geostatistical analysis to describe spatial variability (Chang et al., 1999; Thompson and Seber, 1996; Wollenhaupt et al., 1997). However, many farmers and researchers view grid sampling as costly, unprofitable, inaccurate if grid distances are too large, and inefficient. To improve efficiency and reduce sampling costs, professional agronomists and scientists are dividing fields into management zones. Management zones are areas where weed, insect, or nutrient concentrations are considered uniform, and can be based on landscape position, soil type, yield potentials, prior history, or aerial photographs. However, adopting nutrient management zones is not recommended for fields where:

(i) field histories are unknown;

(ii) fertility levels are high or high rates of fertilizer have been applied;

(iii) manure was applied or the field contained a feedlot;

(iv) small fields were merged into a larger one; and

(v) nonmoble nutrients are important to map (Franzen et al., 1998).

Research during our first year showed that:

(i) many fields fit these criteria, and therefore techniques are needed to define areas where differential management occurred;

(ii) soil electrical conductivity information as measured by an EM meter combined with elevation information can be used to identify areas that received differential management; and

(iii) once these areas are identified, they can be sampled separately from the rest of the field.

The management zone concept will be tested in production fields during the 2^{nd} and 3^{rd} years of the study. Findings from this project will be published in refereed journals and used to develop: (i) educational videos; (ii) middle and high school curricula; (iii) fact sheets; (iv) revisions of the *Site-Specific Management Guidelines*; and (v) articles that will be highlighted on the SDSU Precision Farming Web page.

Nature, scope, and objectives of the research

Theoretically, precision farming is the process of using information to develop more profitable and environmentally sound management systems. Key questions in precision nutrient management are: (i) can I reduce the cost associated with collecting soil nutrient information; (ii) can I quickly process information into decisions; and (iii) can management practices designed to account for soil spatial variability improve environmental quality? A guiding concept behind this project is that science-based sampling and decision tools can minimize the cost of obtaining information and also facilitate the conversion of information into improved decisions.

The objectives of this project are:

1. To determine the influence of pedogenic processes on soil electrical conductivity.

2. To develop and field test an on-the-go soil sensor. The on-the-go soil sensor will be developed by linking pedogenic process models with a survey grade DGPS and an electromagnetic conductivity (EM) sensor. Field testing will include measuring the impact of the sensor on agronomic profitability and estimating, using LEACHEM, the impact of variable rate management on water quality.

The project described below is a three year project. During the first year of the project, object 1 was completed. During years 2 and 3, objective 2 will be completed.

Methods, procedures, and facilities

Methods Objective 1: During the first year of this three-year study, representative landscapes in South Dakota were selected for characterization. At each site, a detailed topographic survey was conducted. At representative locations in the different landscape positions, soil samples from each horizon were collected. Soil samples were analyzed for soil salinity, cation exchange capacity (CEC), plant available nutrients (N, P, K), pH, and soil texture (clay, sand, and silt) by standard techniques. In addition, detailed soil characterization was conducted by USDA-NRCS. Long term climatic information for each site was obtained from the appropriate USDA-NRCS soil survey report and local weather station data. Findings from this study were used to construct conceptual models relating landscape position to N and P availability.

Methods objective 2: In the second and third years of the study, field experiments will be conducted at the Southeast Experimental Farm (Beresford, SD) and a farmers field located near Flandreau. These studies will test the impact of management zone sampling on corn and soybean profitability. Fertilizer (N, P, and K) treatments will be applied during the year that corn is planted. The fields are approximately 65 ha in size; have not received manure for at least 5 years; follows a corn and soybean rotation with half of each field planted to corn and the other half planted to soybeans.

The field experiment will consist of four treatments arranged in a randomized block design. Each crop within a field will contain at least 6 blocks. The treatments will be: (i) N and P fertilizer recommendation based on the whole field average nutrient concentration; (ii) N and P fertilizer recommendation based on grid soil sampling; (iii) nutrient recommendation base on intrinsic and management induced variability as predicted by an on-the-go sensor (P) and landscape position (N); and (iv) unfertilized controls. The anticipated plot sizes will be 20 by 100, however the actual size will depend on equipment and field dimensions. The fields will be harvested by a combine equipped with a yield monitor and plant samples will be collected from each plot. Plant samples will be analyzed for total N and N mass balance will be conducted.

The approach described by Franzen et al. (1998) will be used to identify N management zones. Phosphorus management zones will be identified by an on-the-go sensor.

On-the-go sensor: The P sensor will consist of three components which include: (i) a survey grade DGPS system capable of cm accuracy in the vertical orientation, (ii) electromagnetic sensor (EM 38) which measured soil electrical conductivity, and (iii) a computer information processor that contains mapping and mathematical model software. The model relating apparent electrical conductivity (EC_a) to topography was derived in Objective 1.

The Geonics EM 38, mounted on a wooden trailer, and Leica single frequency survey grade DGPS will be used to determine the soil electrical conductivity and elevation at over 10,000 points in each field. In the EM 38 (Geonics, Ltd. Mississauga, ON, Canada), an alternating current generates a secondary electromagnetic field that is measured by the second coil (Borchers et al., 1997). The amount of current measured at the second coil is related to soil electrical conductivity.

The elevational, latitude, and longitude information will be collected by a Leica (Leica Inc., Norcross, GA) single frequency DGPS system. Data acquisition mode will be real time/ moving. Vertical error for this system and acquisition mode was measured and is less than 5 cm (Johansen et al., 1999).

Analysis: Analysis of variance (ANOVA) will be used to compare yields of the different recommendation approaches. Geostatistics will be used to evaluate sampling distances and regression analysis will be used to evaluate the relationship between different measured values.

The impact of smart sampling protocols on water quality will be evaluated by two approaches. First, total N loading of each plot will be measured. The total N loading will be compared to crop N removal and residual N remaining in the soil. Second, fertilizer application rates, crop yields, crop N removal, and soil N concentrations will be entered into a Geographic Information System (GIS) program. Using GIS, the fertilizer applied, N removal, initial and end of growing season inorganic N will be mapped. These values will be used to validate a simulation model such as LEACHEM (Wagenet and Hutson, 1992) which will then be used to estimate nitrate leaching below the rootzone for the different treatments.

Facilities: South Dakota State University has the equipment required to conduct the proposed research. Equipment available include: Geonics EM38, Leica survey grade real time DGPS, Omnistar DGPS, weather stations, TDR, combines equipped with yield monitors and GPS, HPLC, GC, Europa ratio mass spectrometer, Astoria N analyzer series 300, computers with GIS and ERDAS software, and a portable radiometer produced by CID that scans the 300 to 950 nm wavelengths. A collaborator, Aeroborne Data Systems, has an airplane with a GPS/computer controlled digital remote sensing cameras. The remote sensing and GIS laboratories have 500 MHZ pentium PCS with windows NT operating systems. Multiple copies of both ARC/Info and ERDAS software reside on PCs with University works stations. Supported hardware includes color plotters and printers, 8 mm tape drive, CDrom writers and access to other university resources.

Related Research

A survey in eastern South Dakota was conducted to determine if the proposed sensor could improve the location of N and P management zone boundaries. The survey consisted of 10 spatially sampled fields. In all fields: (i) there were areas with very high or very low P concentrations; (ii) the P median was less than the mean; and (iii) the P skewness values were positive (Table 1). The Moody field, which was sampled in 1995 and 1997, had an old feedlot/homestead on a summit areas located in the west central side of the field (Figure 1). The feedlot was abandoned during the 1930's, and manure had not been applied to the field for the past 15 years. Associated with the feedlot were very high P and K concentrations and elevated pH values.

The Brookings field, sampled in 1996, had two feedlot/homestead locations. These feedlot/homestead sites were located at summit landscape positions (Figure 2). One site was located on the south central part of the field while the other was located on the north eastern part of the field. The old homestead in the south central area was removed in 1997 and the old feed lot located in the north eastern corner has been farmed for at least 15 years. Elevated P concentrations were found in both areas. The high P concentrations of these areas had a profound impact on the fields P probability distributions and are responsible for the high variance.

The Beresford field had an area where high rate of manure was applied to the south central part of the field between 5 and 10 years ago. Soil samples collected in 1997 and 1998 from this area showed that this area still has very high P concentrations. Between 1997 and 1998, the P average concentration remained relatively constant. However, the variance was reduced from over 1600 to less than 550. Similar reduction in the skewness, kurtosis, nugget, and sill values were observed. These reductions may be the result of the incorporation of precision treatments in this field, i.e., P was not applied where it was not needed.

The Flandreau field had an area where high a high rate of manure had been applied several years ago. In this area, very high P concentrations were measured in 1997 and again in 1998. From 1997 to 1998 the average and median P concentration increased while the variance decreased. Similar hot spots were observed in the other sampled fields (50-51, Dave1, Dave2, Weldt W, Larry 1, and Larry 9). In summary, fields containing nutrient hot spots were the norm not the exception and an economic, GIS, and simulation analysis of these sites showed that in order for the management zone concept to provide useful information, the management induced hot spots must be identified and sampled separately. This survey showed that South Dakota farmers and researchers need a sensor, such as one being developed in this project, to help identify management zone boundaries.

Table 1: The means, medians, variances, skewness and kurtosis values of Olsen P for 10 fields located in eastern South Dakota.

Phosphorus Distribution Measurements (&g/g)							
Field Identification	Mean	Median	Variance	Skewness	Kurtosis	Nugget	Sill
Moody 95	13.1	11	59.5	1.7	6.4	27	61
Moody 97	13.6	12	37.2	1.3	4.3	25	40
Brookings 97	18.1	15	268.1	6.2	56.8	70	315
Beresford 97	25.3	12	1610	4.2	23.7	653	3100
Beresford 98	28.9	19	549	1.8	5.7	143	852
Flan 97	13.8	12	52.2	1.2	4.7	35	66
Flan 98	15.1	14	47.0	1.4	5.5	38	49
50-51	13.9	12	45.7	1.2	3.7	50	53
Dave 1	16.0	13	96.3	1.8	7.2	86	95
Dave 2	16.9	15	97.0	0.5	2.1	94	110
HeldtW	7.4	6	18.9	3.1	13.5	14	22
Larry 1	30.7	27	247	0.6	2.3	184	266
Larry 2	25.4	23	95	1.3	3.8	55	86

Separating Management and Intrinsic Variation

Research shows that electromagnetic sensors (EM) are influenced by many soil properties including salt concentrations, water content, tillage, bulk density, and temperature (Drommerhausen et al., 1995; Hanson and Kaita, 1997, Hendrickx et al., 1992; Borchers et al., 1997; Fritz et al., 1998; Lesch et al., 1998; Kachanoski et al., 1988; Sudduth et al., 1995; Jaynes, 1995). Because EC_a is impacted by many factors, techniques are needed separate the individual component from each other. In young glaciated soils developed in low rainfall environments this may be possible because water and salt concentrations tend to be similar or higher in toeslope than summit areas (Malo and Worcester, 1975). This is important because it means that areas with high apparent electrical conductivity will be high at all sampling dates and areas with low apparent electrical conductivity will be low at all sampling dates.

The Moody, Brookings, and Flandreau fields (Figure 1 and 2) were used for a preliminary study to determine if electromagnetic sensors can be used as a directed soil sampling tool in whole fields having varied histories. In these fields, soil samples were collected from from at least a 60 by 60 m grid. Elevation was measured by a survey grade single frequency DGPS, and apparent electrical conductivity (EC_a) was measured between 2 to 4 times in each field between 1995 and 1999 by an EM 38. The EC_a from the different sampling dates were positively correlated to each other because areas with high EC_a values are high at all sampling dates while areas with low EC_a values are low at all sampling dates.

As previously discussed, soil P was highest in areas where manure had been applied. At grid points along transects in the Moody and Brookings fields, where Olsen P < 15 &g/$^{-1}$, EC_a and elevation were negatively correlated. The relationship between EC_a and elevation was used to calculate $EC_{calculated}$ values at sampling points located on transects that passed through low and high P zones. The difference between the $EC_{calculated}$ and measured EC_a was defined as
EC_a, which was postively correlated to Olsen P in both the Moody and Brookings fields (Figure 3). In a practical sense this research indicates that the impact of landscape position on EC_a can be estimated by superimposing the EC_a map on a topography map, and areas that need to sampled separately from the rest of the field can be identified by locating areas where EC_a is higher than expected (Figure 3).
fig 2

References

Borchers, B., T. Uram, and J.M.H. Hendrickx. 1997. Tikhonov regularization of electrical conductivity depth profiles in field soils. Soil Sci. Soc. Am. J., 61:1004-1009.

Chang, J., D.E. Clay, C.G. Carlson, J. Lee, D.D. Malo, S.A. Clay, and M. Ellsbury. 1999. Selecting precision farming soil sampling protocols; Part 1. Grid distance impact on semivariograms and estimation variances. Prec. Farm (In press)

Drommerhausen, D.J., D.E. Radcliffe, D.E. Brune, and H.D. Gunter. 1995. Electromagnetic conductivity surveys of dairies for groundwater nitrate. J. Environ. Qual. 24:1083-1091.

Franzen, D.W., L.J. Cihacek, V.L. Hofman, and L.J. Swenson. 1998. Topography-based sampling compared with grid sampling in the Northern Great Plains. J. Prod. Ag. 11:364-370.

Fritz, R., T.E. Schumacher, D.D. Malo, D.E. Clay, S.A. Clay, C.G. Carlson, M.M. Ellsbury, and K.J. Dalsted. 1998. Field comparison of two soil electrical conductivity measurements systems. Proceedings of the 4th International Conference on Precision Agriculture. July 19-22 1998, St. Paul, MN.

Hanson, B.R. and K. Kaita. 1997. Response of electromagnetic conductivity meter to soil salinity and soil-water content. J. Irr. Drain. 123:141-143.

Hendrickx, J.M.H., B. Baerends, Z.I. Raza, M. Sadig, and M.A. Chaudhry. 1992. Soil salinity assessment by electromagnetic induction of irrigated land. Soil Sci. Soc. Am. J. 56:1933- 1941.

Jaynes, D.B. 1995. Improved soil mapping using electromagnetic induction surveys. P.C. Robert et al. (eds.) In *Site-Specific Management for Agricultural Systems*. ASA-CSSA-SSSA, Madison WI.

Johansen, D.P., D.E. Clay, C.G. Carlson, K.W. Stange, S.A. Clay, and K. Dalsted. 1999. Selecting a DGPS for making topography maps. #14 Clay et al. (ed), *In Site-specific Management Guidelines*. Postash and Phosphate Institutute, Norcross, GA.

Kachanoski, R.G., E.G. Gregorich and I.J. Van Wesenbeeck. 1988. Estimating spatial variations of soil water content using noncontacting electromagnetic inductive methods. Can J. Soil Sci. 68:715-722.

Larson, W.E., J.A. Lamb, B.R. Khakural, R.B. Ferguson, and G.W. Rehm. 1997. Potential of site-specific management for nonpoint environmental protection. In Pierce and Sadler (ed) *The State of Site Specific Management for Agriculture*. pp 337-369. ASA, CSSA, and SSSAJ. Madison WI.

Lesch, S.M., J. Herrero, and J.D. Rhoades. 1998. Monitoring for temporal changes in soil salinity using electromagnetic induction techniques. Soil Sci. Soc. Am. J. 62:232-242.

Malo, D.D. and B.K. Worcester. 1975. Soil fertility and crop responses to selected landscape positions. Agron. J. 67:397-401.

Romkens, K.G. and D.W. Nelson. 1974. Phosphorous relationships in runoff from fertilized fields. J. Environ. Qual. 3:10-13.

Sudduth, K.A., N.R. Kitchen, D.F. Hughes, and S.T. Drummond. 1995. Electromagnetic induction sensing as an indicator of productivity on claypan soils. p. 671-581. In P.C. Robert et al. (eds.) *Site Specific Management for Agricultural Systems*. ASA Misc. Publ. ASA, CSSA, and SSSA, Madison, WI.

Stevenson, F.G. 1986. Cycles of soil. Wiley, New York.

Thompson, S.K. and G.A.F. Seber. 1996. *Adaptive Sampling*. Wiley and Sons Inc. New York.

Wagenet, R.J. and J.L. Hutson. 1992. LEACHM: Leaching estimation and chemistry model. A process-based model of water solute movement, transformation, plant uptake, and chemical reactions in the unsaturated zone. Version 3. Dep. of Soil Crop and Atmospheric Science. Res. Series No 92-3. Cornell Univ. Ithaca, NY.

Wollenhaupt, N., C., Wolkowski, R.P. and Reetz Jr., H.F., 1997. Variable rate fertilizer application: update and economics. In R.M. Vander Hewel (ed), *Information*

Gathering: Precision Agriculture and Intensive Soil Sampling. Cenex Land O'Lakes,

Agronomy Technical Services/Agrisource Laboratories. Inner Grove Heights, MN.

Information transfer plan:

This project will develop products that will be disseminated by a precision farming technology transfer project funded by SD DENR. The following is a description of this project. The goal of the IT component of this project is to develop and refine educational materials that demonstrate how 21st Century technologies can be used to reduce agriculture impacts on the environment and improve agronomic profitability. The materials developed will provide information that farm managers need to reduce the economic and environmental risk associated with individual decisions. Materials that will be developed include: (i) videos that demonstrate resource management concepts that can be shown at farmer workshops, in the classroom, or on television; (ii) curricula for middle and high school students; and (iii) fact sheets that address specific topics, and (iv) improving and revising guidelines in the *Site-Specific Management Guideline Manual*.

Objective 1. Produce videos that demonstrate resource management principals. The videos will show how 21st Century Technology can be used to help solve resource management problems. The videos will be produced in short 2 or 3 minute sections which can be shown separately or combined into a full length video. Videos may consider the follow topics:

- How do yield monitors work?

- How will the 21st century technologies influence rural and urban communities?

- What is an EM meter and how can we use it to define management zones?
- How will precision farming influence water and air quality?
- What technologies are available to reduce the impact of a animal agriculture on urban

  communities?
- What is soil, why is it variable, and how can we manage variability?

Objective 2. Develop resource management curriculum materials for middle and high schools. Because students are the managers, farmers, ranchers, and citizens of tomorrow, it is important that they learn about the tools available for prudent management of our natural resources.

Task 1: Conduct a workshop for middle and high school teachers during the summer of 2000. In the workshop 20 to 25 South Dakota middle and high school teachers will learn how to utilize geographic referenced information, geographic information system software (ArcView), remotely sensed imagery, and global positioning systems (GPS) as tools for managing natural resources. South Dakota is in the initial stages of planning a two-week workshop for June 2000. The workshop is tentatively scheduled at the EROS Data Center to take advantage of their facilities, personnel, and data resources. At the workshop, teachers will:

1. Develop resource management curriculum using spatially referenced information, GIS and GPS; and
2. Share their knowledge and experiences with other South Dakota teachers.

Objective 3 Develop educational materials for K-12 teachers that will be distributed through existing statewide programs (SDSU Web Page, Ag in the Classroom, and the Natural Source).

Task 1: Develop fact sheets that will be distributed to school teachers, vocational education teachers, farmers, and the general public. It is critical that educators and the general public as well as farmers become knowledgeable of the role and concerns that agriculture places on environmental safety, economics, and good stewardship of our natural resources. Most people have limited exposure or familiarity with modern agricultural systems, agricultural science, and the role that new technologies will play in improving the management of natural resources. It is critical that urban and rural South Dakota communities understand the importance of agriculture. Topics discussed in fact sheets will include:

- Site-specific management;

- New technology for agriculture (GPS, GIS, Variable rate technology);
- The role of site-specific farming on environmental quality; and
- What is manure and how can we manage it.

Approximately 1000 copies of each fact sheet will be printed. Fact sheets will be distributed to interested teachers and electronic copies will be available on WEB home pages. Estimated cost for this objective is $3,000 (PPIS $3,000)

Objective 4: Use experts from throughout the Midwest to create site-specific management guidelines based upon current scientific understanding.

Task 1: During the past year, the *Site-Specific Management Guideline* Manual was developed. This manual contains 29 individual guidelines. During the next year, 4-5 new guidelines will be developed and many of the current guidelines will be revised. Current up-to-date guidelines are needed because new technologies are changing the way agricultural managers make decisions. Even though many new technologies have not been fully evaluated, farm managers are searching for guidance on how to use them. Research activities in the proposed project are critical toward furthering this knowledge.

The result of this task will be an updated and improved assemblage of guidelines on various topics bound in a three-ring binder. Each guideline will have a common format, patterned after the National Corn Handbook. The guidelines will be available from Potash and Phosphate Institute, South Dakota Extension Service, and in electronic format on the internet.

Guidelines will be: (i) peer-reviewed; (ii) provide an avenue for information collected on a regional level to be disseminated to South Dakota practitioners; (iii) provide a central location for the collection of precision farming agricultural management recommendations; (iv) identify gaps in the knowledge base, and (iv) provide practical recommendation that can be used by farmers to improve profitability and reduce the impact of agriculture on the environment.