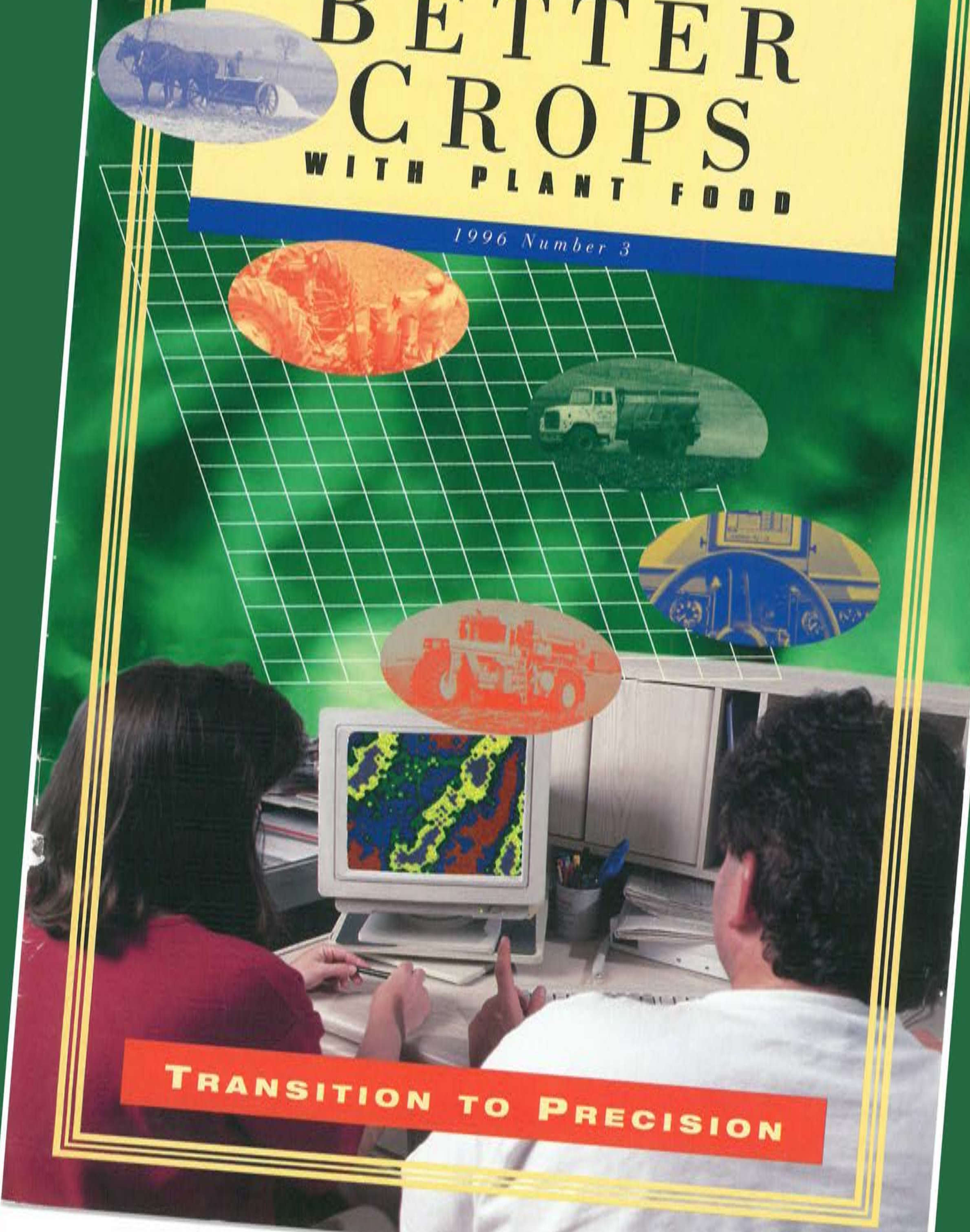
BETTER CROPS WITH PLANT FOOD

1996 Number 3



TRANSITION TO PRECISION

BETTER CROPS
WITH PLANT FOOD

Vol. LXXX (80) 1996, No. 3

Our Cover: Production agriculture continues on a changing path to more precise management.

Design: DesignRT

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CONTENTS

AN ECONOMIST'S VIEW

Is Precision Farming Good for Society?

By Luther Tweeten

In our market economy, technology isn't adopted by firms unless benefits exceed costs. The articles in this issue show many advantages of precision farming for production agriculture, and the technology seems destined to pass the profitability test on large numbers of farms. But it is well to go beyond the farm to examine whether precision farming is good for society on national economic, social and environmental grounds.

National Economic Impact

The nationwide economic impact of precision farming will depend on whether the technology mainly saves inputs and costs or mainly increases output. By combining soil test, seeding rate, yield, pesticide and fertilizer application data for hundreds of plots per farm, precision farming offers unprecedented "experimental" data. Such data more precisely dictate optimal economic input and crop

Dr. Paul E. Fixen Appointed PPI North American Program Coordinator

Dr. Paul E. Fixen of Brookings, South Dakota has been named North American Program Coordinator and Director of Research in North American Programs for PPI. His new responsibilities begin immediately.

Announcement of the promotion came from Dr. David W. Dibb, President of PPI. "Paul Fixen has been a valuable asset to PPI with his work in the Northcentral region and we know he will be an even greater asset in his new role," Dr. Dibb emphasized.

A native of Minnesota, Dr. Fixen received his B.S. and M.S. degrees at South Dakota State University in Agricultural Education and Soil Fertility, respectively. He earned his Ph.D. degree at Colorado State University in 1978 with a specialization in soil fertility, plant nutrition and soil chemistry. Dr. Fixen joined the staff of PPI in 1989 as the Northcentral Regional Director and has served Minnesota, Iowa, North Dakota, South Dakota, Montana, Kansas and Nebraska.

Dr. Fixen and his family will continue to reside in Brookings. An office will be established there for coordination of the Institute's agronomic research and education programs in North American regions. BC yield. As a result, producers achieve greater crop output per pound of fertilizer, seed and pesticide. If the enlarged output-input ratio comes from using less fertilizer and other inputs, it will cut farmers' costs and save natural resources. Such an outcome is anticipated by Clayton Ogg (*Choices*, First Quarter 1996, pp. 37-38) who cites various studies showing nitrogen (N) application could be cut 24 to 40 percent with improved crediting of farm-produced N alone. Eventually, cost-saving benefits will be bid into land prices.

If the greater output-input ratio does not save fertilizer and other inputs but instead comes as greater output, the result will be lower crop and food prices benefiting consumers. Benefits are relatively largest for low income families because they spend a high proportion of their income for food.

In reality, economic benefits of precision farming are likely to come from more efficient use of inputs and from additional farm output. Successful early adopters of precision farming gain the most because they produce before output prices fall. As more farmers adopt, output expands and commodity prices fall, passing benefits to consumers. Farmers who do not adopt as crop prices fall will lose from precision farming. Based on historic experience with technology, I conclude that more of the long-term economic benefits of precision farming are likely to accrue to consumers than to land owners.

Precision farming will be widely adopted because it is profitable on individual farms. However, in this era of skeptics questioning all manner of technology, scientists also must examine the broader economic, social and environmental consequences. On that basis, precision farming receives mostly high marks.

Social Impact

The social impact of precision farming on family farms and rural farm communities depends heavily on what it does to (1) economies of size...costs of production on large versus small farms and (2) labor requirements in farming. Precision farming can be as effective on an acre on a small farm as on a large farm. But economies arise because precision farming requires lumpy inputs: investment in machinery, equipment, grid mapping, soil testing and the like. Computer controlled seed, fertilizer, and pesticide application equipment requires operating and maintenance skills. A custom operator or cooperative could serve several small farms, no one of which could afford a standalone precision farming system. But custom precision farming operators will have lower transaction and setup costs per acre when they can work on larger fields and with large farms. Thus some economies of size will accrue to bigger operations, and many small operators will not adopt precision farming because it is too costly or too much bother.

Nonetheless, I conclude that precision farming will have a small impact on farm structure compared to the tractor or combine. First, precision farming does not save labor so farms will not need to expand to better utilize each operator's labor. Second, many small farms will be able to share in economies of size through hiring of custom operators or working with cooperatives. Finally, numerous part-time small farm operators, although slow to adopt cost-saving precision farming, will not be driven out by losses from higher land costs or lower commodity prices caused by widespread adoption of precision farming by other operators. The reason is that most part-time small farm operators are driven by lifestyle rather than profit – as evident from the fact that most lose money farming and support their farming avocation with off-farm income.

Turning now to impacts on rural communities, an important principle is that rural people shift their shopping to larger towns and cities as income rises. Some commercial farmers doing well from precision farming will shift their shopping to larger communities. But the rural community impact of precision farming will not be great because the impact on farm size, numbers and population will not be great.

Environmental Impact

Principal environmental problems of agriculture include water, air and food quality, and natural resource depletion. Conventional blanket application of fertilizer means excessive application on some areas and inadequate application in other areas in the field. Application in excess of plant uptake causes surplus effluent to be carried away into groundwater or surface water. If, as some experts believe, producers on average will apply less fertilizer under precision farming nutrient runoff is likely to be less with precision farming. Reductions in fertilizer use are unlikely to be large, however, because conventional blanket rates often shortchange plots giving high fertilizer response. In such cases, fertilizer use will increase.

Pesticide savings will be more common than fertilizer savings, because producers often apply blanket pesticides to fields requiring only spot treatment. Some operators successively blanket fields with one pesticide to kill one weed or bug and another pesticide to kill another pest. Sensors and mapping could better tailor the type, volume and location of pesticide application to site-specific needs.

Precision farming is likely to raise productivity of land, decreasing land requirements to meet food and fiber demand. This frees land for species preservation, wildlife, trees, grazing and other uses consistent with soil conservation and a sound environment. Precision farming can help to achieve uniformly robust crop stands, providing a cover against erosion.

Site-specific control offered by precision farming could tailor chemical application to ameliorate environmental hot spots. According to a survey from the U.S. Environmental Protection Agency (EPA), 2 percent of rural wells contain nitrate levels and 0.6 percent of wells contain pesticide levels in excess of EPA safety standards. Precision agriculture may provide a means to reduce application on sites contributing to such water quality problems.

Conclusions

Is precision farming good for society? Based on what we know now, precision farming will save natural resources and/or reduce food prices to benefit consumers. More precise chemical applications can reduce contamination of water and food. Compared to the tractor and its complements, precision farming will not displace many farms or farm families. Of course, much remains to be learned about precision farming, and scientists around the country are seeking more answers. BC

Dr. Tweeten is Anderson Professor of Agricultural Marketing, Policy, and Trade, Department of Agricultural Economics, The Ohio State University, Columbus, Ohio. *Comments of Jeff Hopkins, Gary Schnitkey, and Carl Zulauf are appreciated.*

MINNESOTA

Corn Yield Response Variability and Potential Profitability of Site-Specific Nitrogen Management

By Gary L. Malzer

Precision farming is attracting a great deal of interest among producers, industry and the public sector. Although the methods of precision farming can be used with any agricultural input (cultivar selection, plant population, pest control, etc.), its origin was with soil fertility and nutrient management. Applying nutrients at rates according to plant need has the potential to increase profitability for the producer, and in certain cases may reduce nutrient loss and lessen the environmental impacts associated with nutrient application. The challenge is to interpret field spatial variability in a manner that will allow the most profitable rates of application without over-fertilization.

The potential profitability of site-specific nitrogen (N) management depends on predicting the spatial variability of profitability of N use. Four studies conducted over two years showed that profitability of N use varies widely across landscapes. The potential profitability of site-specific N management ranged from $4 to $37 per acre.

Minnesota Studies

Four experiments were conducted on production corn fields in southern Minnesota during 1994 and 1995 to determine the potential for site-specific N rate management. Six replications of six constant N rate treatments were applied as strips across the fields. Geo-referenced grain yields were obtained from 50 ft. continuous segments from each treatment strip. Regression techniques were used to fit fertilizer N response curves within small regions composed of groups of yield segments. From the response curves, the economic optimum N rate (EONR) and profitability of N use were calculated specific to each small region.

The economic analysis used prices specific to each growing season. Nitrogen prices were based on fall-applied anhydrous ammonia (12¢/lb in 1994 and 17¢/lb in 1995) and fall cash prices were used for corn ($2.00/bu in 1994 and $3.00/bu in 1995). This year's higher prices have little impact on the calculated EONR but will result in substantially increased profitability of N use.

DOES FIELD VARIABILITY WARRANT DIFFERENT RATES OF N? Crop response to applied fertilizer N was variable across the landscape at all locations in each of the two years. Some areas within a field showed little or no response to fertilizer N, while other areas required substantial amounts of N to attain the most economic yield. **Figure 1** provides a spatial representation of the amount of N required to attain maximum economic yield (MEY) at Hanska, Minn., in 1994.

FIELD AVERAGES DO NOT TELL THE ENTIRE STORY. Each field is unique. At

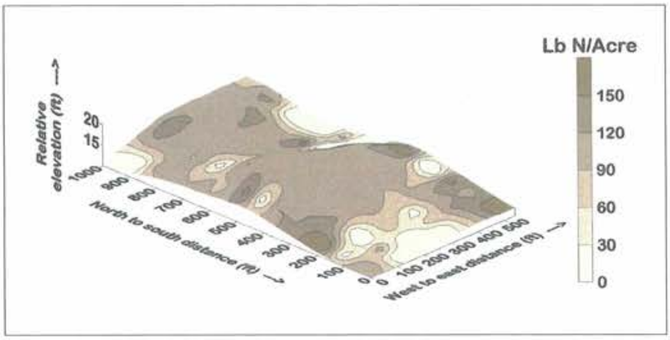

FIGURE 1. Topography and spatial distribution of EONR within a 12-acre portion of a corn field. (Hanska, Minn., 1994)

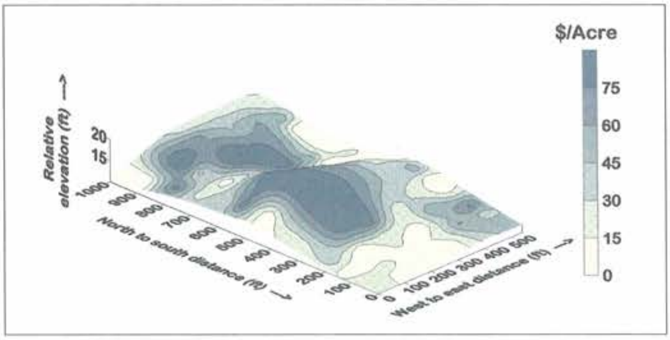

FIGURE 2. Topography and spatial distribution of profitability of N use within a 12-acre portion of a corn field at Hanska, 1994.

Hanska in 1994 the EONR was 40 lb/A less fertilizer N than recommended by the University of Minnesota. A summary of all four locations (**Table 1**) suggests that the average rate of N needed on some fields may be lower than current recommendations while other fields may require more. All locations did, however, show a wide range of optimum N rates around that average.

Variability in EONR led to under-fertilization and over-fertilization of large portions of each field (**Table 2**). Under-fertilized areas cost the producers potential income, while over-fertilized areas waste fertilizer and might cause environmental problems. Adequately fertilized areas were defined as those areas of the field within a 30 lb/A window (plus or minus 15 lb/A) of the current recommendation. Even within the fields where the current recommendation was similar to the weighted average rate required using optimum site-specific management, the amount of the field adequately fertilized was less than 50 percent.

Profitability is not uniform. As field variability in EONR is considered, there is no reason to think that profitability of N use will be constant within a field. Profitability of N use was calculated as the increased value of yield minus the cost of the N

TABLE 1. Weighted field average and range of N rates (EONR) required to attain MEY as compared to current uniform recommendations.

	Fertilizer N rates		
	Variable site-specific		Constant
Location	Range	Average	recommendation
		lb/A	
Hanska1994	0-180	89	130
Hector 1994	92-180	142	150
Hanska 1995	108-180	138	130
Morgan 1995	135-180	168	130

TABLE 2. Percent of field area that would have been under-fertilized or over-fertilized with recommended uniform application rates of N.

	Percent of field area and rate				
	Over-fertilization		Under-fertilization		Adequate
Location	%	lb/A	%	lb/A	%
Hanska1994	72	42	7	4	21
Hector 1994	56	18	36	11	8
Hanska 1995	29	5	29	12	42
Morgan 1995	0	–	75	36	25

fertilizer on a per acre basis. The spatial distribution pattern of profitability did not match that of EONR (**Figure 2**). The range across the landscape in profitability of N use was wide at all locations (**Table 3**). Focusing on the areas of the field that show the most profitability of N use may be more successful than attempting to match the EONR at every point in the landscape. The potential returns of the ideal site-specific recommendation in comparison with a constant rate recommendation ranged from $4 to $37 per acre.

Needs for the future

The ability to attain the potential profitability of site-specific N rate management will depend upon accurate N rate predictions related to site-specific profitability of N use. Since the rate of N required to provide maximum profitability (EONR) varied widely within each field, the procedure used to predict that rate must also be sensitive to site-specific conditions. Factors currently used to make N recommendations, such as the use of appropriate yield goals, previous cropping histories, organic matter content, and even residual nitrate N, were capable of predicting only a portion (seldom more than 50 percent) of the potential benefit of site-specific management. Additional factors will need to be considered in order to develop spatial relationships that maximize the profitability of site-specific N management. BC

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Acknowledgments: *The author wishes to acknowledge the contributions of P.J. Copeland, J.G. Davis, T.W. Bruulsema, T. Graff, J. Lamb and P.C. Robert to this project. Appreciation is also extended to the producers, fertilizer dealer agronomists, and industry technical support. Major funding provided by the Department of Energy via the Legislative Commission on Minnesota Resources.*

TABLE 3. Range and average of profitability of N use associated with site-specific N rate management compared to recommended constant rate of application.

	Profitability of N use			
	Variable site-specific		Constant rate	
Location	Range	Average	recommendation	Difference
	$/A			
Hanska1994	0-88	42	38	4
Hector 1994	11-200	90	79	11
Hanska 1995	56-217	127	118	9
Morgan 1995	103-233	176	139	37

Maintenance + Buildup Nutrient Management for Site-Specific Systems

By H.F. Reetz

In applying the maintenance + buildup system to site-specific management, it is important to understand system components and how they may be affected by a more intensive management plan.

Maintenance

The maintenance component involves applying nutrients to the soil in proportion to the amounts removed in the harvested crop. Standard tables can be used. More accurate estimates result from the analysis of grain or forage removed from the field. Variations in genetic makeup, weather conditions, and management factors often significantly influence the actual nutrient removal by the crop. Adjustments are made to account for crop residues and manure added back to the soil.

One of the more popular nutrient management concepts, especially in the Midwest U.S., is the **Maintenance + Buildup System**. This approach lends itself well to site-specific nutrient management, because it allows for separate consideration of the soil test level and the crop removal components of nutrient management.

The maintenance application can be made annually, but more commonly an estimate is made of the total nutrient removal for all crops in the rotation and applications made accordingly, often once in the rotation cycle. If soil tests are being maintained at levels supportive of optimum yields for all crops, adjustments for any discrepancies between expected yields and actual yields can be made in formulating application rates for the next crop cycle.

Determining yield goals is a critical component of maintenance. It is generally recommended that yield goals be based upon the average of the last 3 to 5 crop years, with some consideration given to known increments of technology and allowance for obvious abnormal growing seasons. When setting yield goals for individual areas of a field, these considerations become even more important because the year-to-year variations due to weather often have greater influence on measured yields for the smaller areas.

Buildup

Where soil test levels are less than optimum for producing maximum economic yields, buildup applications are made in addition to the maintenance application. Rates of buildup nutrient application needed depend upon soil types and the time interval over which the producer would like to extend the buildup period. Soil characteristics affect the amount of nutrients needed to build soil test levels — and the level to which they can be built. The farmer's economic situation, the value of crops to be grown, and the number of years the operator plans to farm the field are among the considerations in determining the time interval over which buildup applications are to be made.

For a silt loam soil in the Midwest, standard buildup estimates are approximately 4 lb/A of K_2O to build soil test K level by 1 lb/A, and 9 lb/A P_2O_5 to build the soil test P level by 1 lb/A. The actual responses for individual soils may be considerably different than these averages. Soil variability, the initial soil test level, the target level, and many other factors affect these estimates. Nutrient and yield records on a given field and the farmer's past experience are important considerations in estimating actual buildup requirements. In some cases, soil characteristics will dictate that the buildup approach is not appropriate due to leaching potential, nutrient fixation by the soil into unavailable forms, and other factors.

Soil Test Goal

A soil test goal is established and nutrients are added to attempt to build soil test levels to reach that goal. Most buildup goals are established in reference to long-term research that has determined the appropriate soil test levels above which the nutrient should not be limiting for the crop to be grown. These levels are different for different crops and soils. Generally, they have been established slightly above the expected crop response range, so that if the level fluctuates during the crop rotation cycle, yields will not be adversely affected. Re-testing at regular intervals, usually every 3 to 4 years, helps determine progress toward the goal.

Some universities, such as the University of Wisconsin, have elected to move the recommended buildup level down to the range where the soil test level plus the annual maintenance application will be sufficient to meet the needs of the crop. This approach results in a lower buildup investment, but makes it much more critical to have accurate yield estimates upon which to make recommendations for maintenance applications.

Site-Specific Systems

As nutrient management switches from a focus on field-average recommendations toward managing different areas of a field differently, there may be less flexibility in the recommendations made for a given field. It is important to keep in perspective that soil tests do not give an actual measurement of nutrient levels in the soil, but rather provide an index of the nutrient supplying capability of the soil. This index is valid only in conjunction with its calibration data that provide the relationship between the index number and the expected yield response, usually based on nutrient-response studies conducted in field plots over a period of years. These relationships were developed with the intention that they would be used for field-average nutrient management decisions. It may take several years' point-sampling and yield monitor data to determine whether these calibration data and soil test indices are appropriate for site-specific management of areas of 1 to 3 acres in size. But for now, they are the best estimates available.

With field-average management, assuming nutrient applications are made according to a sound soil testing program, there is a tendency to increase the variability of soil test levels within the field. Areas of the field producing yields above average will tend to become depleted in nutrients because removal will exceed the average maintenance application rates. Areas producing below-average yields will tend to build soil test levels because nutrient removal will be less than the average maintenance rates. While this may not be a major concern in the short-term, long-term effects can result in reduced yields in the most productive areas of the field and unnecessary expenses and environmental risks from applying excess nutrients to the less productive areas of the field.

With site-specific management, maintenance nutrient applications can be targeted to the variable productivity of the field, so that some of the variability can be removed, but all of it can be managed to be sure nutrients are applied where they will do the most good. This will avoid depletion of nutrients in the most productive parts of the field and eliminate unnecessary buildup of nutrients in the less productive parts of the field.

Sampling for Site-Specific Management

Site-specific management allows maintenance and buildup recommendations to be made for a smaller geographic area of the field, taking into consideration the variability in soil test levels, soil types, topography and variability in yield. Under such a system, buildup applications are based upon soil tests, preferably taken with geographically-referenced sampling points using global positioning systems (GPS). Maintenance applications are determined from yield maps generated from on-the-go yield monitors, with yield data also geographically referenced by GPS systems.

A field-by-field data base of variability in soil test levels, nutrient application over time, and yield for all crops in the rotation can be developed and catalogued in a geographic information system (GIS). The GIS can then be used to aid in the interpretation of the relationships of various nutrient factors to yield and profitability. Areas as small as 1 to 3 acres may be managed separately as if they were individual fields. Individual soil samples collected for site-specific management should be made up of a composite of 4 to 8 cores collected from within a 10 ft. radius of the sample point.

Each sample point should be geographically-referenced and kept separate for analysis and interpretation. Whether the sample points are selected on a uniform grid basis or located by soil type, topography or some other means should be determined by the farmer and his advisers based upon their knowledge of the field. The ability to document soil tests, field observations, and yield with precise geographic coordinates to within a few feet allows for accurate positioning of both analytical data and yield data. Thus, recommendations can be made to adjust for these measurements in making future nutrient applications.

Maps Won't Match

The expectation that crop yield maps will match variability in soil test maps will most likely lead to disappointment. If the field has been managed according to a good soil testing program, soil fertility has likely been eliminated as a major limiting factor in determining yield. Most yield variability is likely to be more directly caused by other factors such as compaction, water management, tillage, pest problems, etc. Furthermore, as discussed above, field average nutrient applications lead to variability that is inversely correlated to yield level.

This does not mean that site-specific sampling and variable-rate nutrient application are not applicable or important. In fact, site-specific nutrient management will, over time, bring the soil nutrient levels more in line with the general productive capacity of the different parts of the field, so that yield maps and nutrient maps may eventually be more directly correlated. BC

Dr. Reetz is PPI Midwest Director located at Monticello, IL.

SASKATCHEWAN

Field Mapping of Soil Nutrient Supply Rates

By Jeff Schoenau and Ken Greer

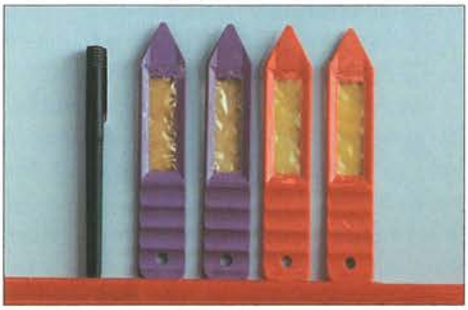
One of the limitations in the adoption of site-specific management techniques such as variable rate fertilization is the effort and resources required to obtain necessary soil information for the site. Information on soil fertility variations in landscapes can be provided by remote sensing, including aerial photographs in which soil color is related to organic matter content and soil fertility. While this approach is simple and relatively inexpensive, it may be limited by the rather indirect relationship that often exists between soil color and fertility. It is also sometimes difficult to get the degree of resolution needed when highly detailed assessments of a field area are desired.

Saskatchewan researchers have developed a simple, rapid system for estimating nutrient availability that may benefit site-specific management.

For intensive field mapping of soil fertility, some sort of direct assessment of soil fertility is usually necessary. Intensive soil sampling of an area, usually on a grid, followed by extraction of the samples with a solution such as dilute calcium chloride or sodium bicarbonate is commonly used to provide a reliable indication of how the amounts of available nutrient (e.g., nitrate and phosphate) present in the soil at the time of sampling vary across the field area. However, it provides limited information on how different locations within the field differ in their ability to supply nutrients in an available form over time under field conditions, especially with regard to mineralization of nitrogen (N) and sulfur (S). As well, the acquisition, handling and processing of many soil samples can be rather cumbersome and time consuming.

Assessing Plant Nutrient Supply Rates

As an alternative to the above approaches, we have developed a simple in-field means of assessing plant nutrient supply rates. The method involves using ion exchange membranes buried directly in the soil to act as plant root simulators to simultaneously adsorb plant available nutrient ions over the burial period. The ion exchange membranes, when chemically pre-treated,



PLANT ROOT simulator probes are used in field measurement of soil nutrient supply rates. Orange probes measure anions such as nitrate, phosphate and sulfate. Purple probes measure cations, including potassium, calcium and magnesium. (Probes by Western Ag Innovations, Saskatoon, Sask.)

exhibit surface characteristics and nutrient sorption phenomena that resemble to a certain extent a plant root surface. The exchange membrane is encapsulated in a plastic probe to create a device we have termed the plant root simulator (PRS) probe, shown in photo.

Direct insertion of the probe into the soil under field conditions allows the many factors which affect nutrient ion flux to roots, including soil texture and structure, to be accounted for in the assessment. During the burial period, nutrient ions adjacent to the probe that are already in the available form along with nutrients that are converted to the available form will be adsorbed onto the surface. The amount of nutrient ion adsorbed on the probe at the end of the burial period is used as a measurement of the potential nutrient ion supply rate to a plant and is expressed in units of micrograms of sorbed nutrient per 10 square centimeters of probe surface over the burial time. We have found that burial times of one hour are convenient for "snapshots" of nutrient ion supply rate, while longer term burials integrate and include more of the factors affecting availability, such as organic matter decomposition rates. For this purpose a burial time of two weeks works well.

Method of Use of PRS Probes

Two types of PRS probe surfaces are available for use: anion exchange and cation exchange. The anion exchange probe will simultaneously adsorb all nutrient anions, including nitrate, phosphate, and sulfate. Cation exchange probes will simultaneously adsorb nutrient cations such as potassium (K), calcium (Ca), and magnesium (Mg). Chelating ion exchange probes can also be constructed to adsorb micronutrient metals including copper (Cn), zinc (Zn), iron (Fe) and manganese (Mn).

In the field at each grid point, a small slot is first made in the soil to which water

THE PRS probes are buried in the soil.

may or may not be added. If one is interested in nutrient supply rate differences which integrate differences in soil moisture content as they exist naturally in the field, then no water is added. On the other hand, to remove differences in nutrient supply rate arising from differences in soil moisture content, a small amount of water may be added to the slot which will bring the soil immediately adjacent to the probe to field capacity. The PRS probe is then inserted into the slot and allowed to remain in the soil for the prescribed period of time. The above photo shows probe placement in soil.

At the end of the burial period, the probe is removed from the soil and washed free of adhering soil in a stream of water. The probe is then placed in a dilute acid or salt solution which strips nutrients off and into solution where they can be measured for nutrient concentration. Depending on the nutrient ion of interest, most or all of these steps could be completed in the field. For our purposes, the most convenient approach has been to simply bring the washed probes from the field back to the research laboratory for analysis.

Making the Map

The PRS data obtained for each grid point in the field is entered into a computer program enabling construction of a map of nutrient supply rate. In the fall of 1995, we constructed such a field fertility map

(continued on page 17)

NORTH DAKOTA

Sampling for Site-Specific Farming: Topography and Nutrient Considerations

By D.W. Franzen, V.L. Hofman, A.D. Halvorson and L.J. Cihacek

North Dakota farmers have begun using site-specific technology to fine-tune fertilizer rates and other production practices. Currently, one of the driving forces behind variable-rate fertilizer application is sugarbeet production. Sugarbeet profits come from both yield and sugar content.

Nitrogen (N) is very important to achieve high yields, but excess N decreases the concentration of sugar and increases impurities, reducing premiums paid to producers. Variable-rate N fertilization has helped maintain high yields while increasing sugar content, making it a highly profitable tool for sugarbeet growers.

Although sugarbeet production is important in eastern North Dakota, many other crops grown throughout the state rely on proper N fertility to produce the yields and quality necessary for grower profitability. They include hard red spring wheat, durum wheat, malting barley, dry bean, canola and potato. These crops are grown on over 80 percent of the non-hay crop land in North Dakota.

Studies in the northern Great Plains are indicating substantial within-field variability of several nutrients. Preliminary indications are that topography may be an important consideration in sampling these fields for variable rate fertilizer application.

TABLE 1. Correlation of zero to 2 ft. NO_3-N in a 110 ft. grid with estimates from less dense grid patterns.

Grid size	Valley City	Gardner
	r	
220 ft.	0.175	0.513
330 ft.	0.065	0.351
5 acres	0.073	0.158

North Dakota has a very successful fall/spring soil nitrate testing program. Because of the long winters, fall or spring nitrate testing is an effective tool that allows producers to predict N needs far in advance of crop production.

North Dakota Studies

Two square 40 acre fields were sampled in the fall of 1994 in a 110 ft. grid. The first field, located near Gardner, represented a typical level Red River Valley landscape. Soil cores were taken to a 4 ft. depth and divided into 0-6 in., 6-24 in., and 24-48 in. increments. Sodium bicarbonate extractable phosphorus (Olsen P), pH, zinc (Zn), organic matter and potassium (K) were determined on the 0-6 in. sample. Sulfate and chloride (Cl) were determined on the 0-6 in. and 6-24 in. samples, and nitrate-N (NO_3-N) was analyzed for all depths. The second field was located south of Valley City and represented the glacial till plain soil groups which are typified by variability in landscape and texture. Soil samples were taken at the 0-6 in. and 6-24 in. depth and analyzed as indicated.

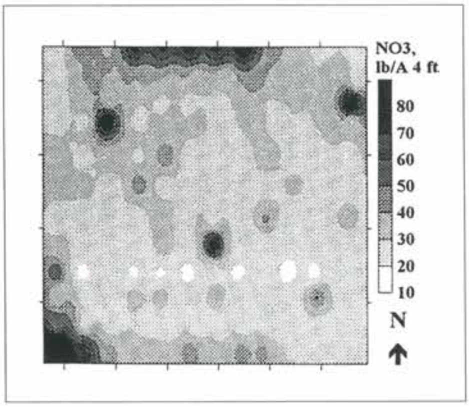


FIGURE 1. Nitrate-N levels at the Gardner field in 1995 varied from 15 to 169 lb/A.

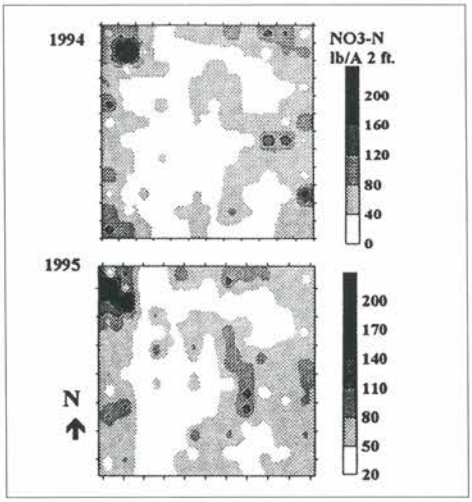


FIGURE 2. Comparison of Valley City nitrate-N between 1994 and 1995.

Sampling at both locations was repeated in the fall of 1995.

In 1995, two additional fields were sampled, a square 40 acre field near Colfax on the western edge of the Red River Valley and an approximately 80 acre field located at the USDA-ARS Research Center near Mandan. Samples were taken from Colfax in the same manner as the Gardner site. Samples at Mandan were taken to a 2 ft. depth and separated as at Valley City. The Mandan site was divided into west, center and east fields. The east field was sampled in a 110 ft. grid, while the center and west were sampled in 150 ft. grids. Maps were produced using inverse distance squared weighting.

Despite the uniform appearance of the Gardner field, NO_3-N levels varied in 1994 from 9 to 274 lb/A in the top 48 in. and 15 to 169 lb/A in 1995 (**Figure 1**). Soil NO_3-N levels seem to follow patterns of surface grading for drainage within the field.

The Valley City field was more variable in topography and nutrient levels than the Gardner field. Nitrate-N levels to 2 ft. varied from 4 to 554 lb/A in 1994

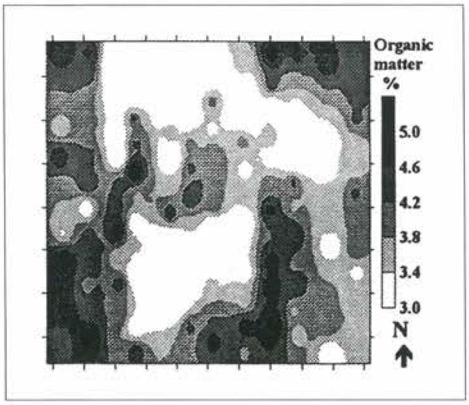


FIGURE 3. Valley City organic matter levels, 1995.

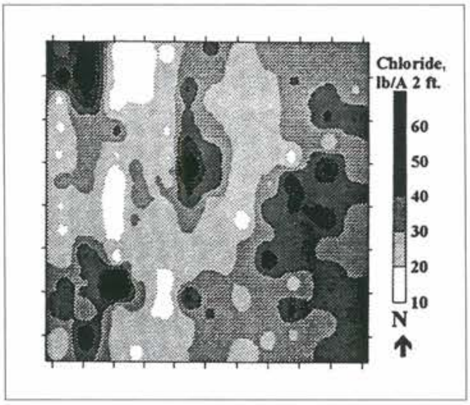


FIGURE 4. Valley City chloride levels, 0-2 ft., 1995.

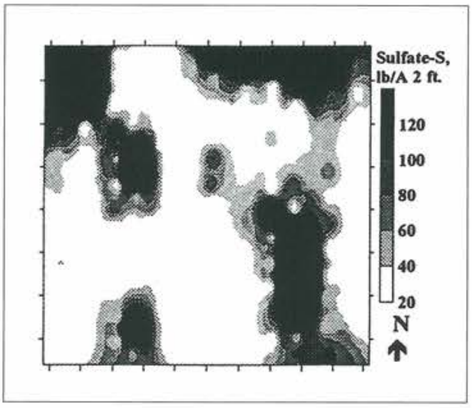


FIGURE 5. Valley City sulfate-S levels, 0-2 ft., 1995.

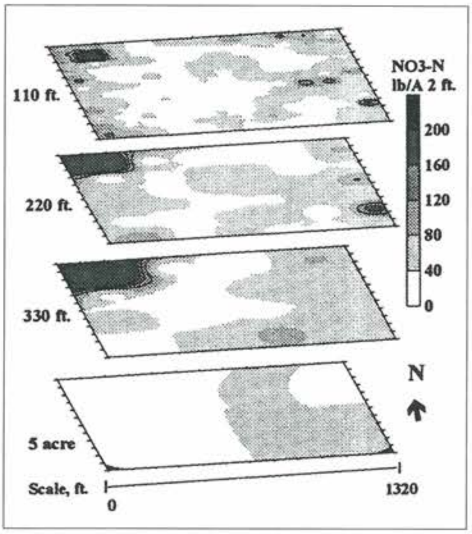


FIGURE 6. Soil nitrate-N, Valley City as represented by different sampling grids.

and 9 to 374 lb/A in 1995 (**Figure 2**). Organic matter content is a reflection of topography at Valley City (**Figure 3**). Valley City NO_3-N levels appear to follow similar patterns to organic matter. Other evidence to support a topographic relationship is the similarity of NO_3-N levels between 1994 and 1995 (**Figure 2**). Similarities are present despite a uniform application of 100 lb N/A and removal of a 2,000 lb/A sunflower crop in 1995. Not only does NO_3-N appear to be related to topography, but Cl and sulfate (**Figures 4 and 5**) also appear to be related to landscape position.

Grid sizes at Gardner and Valley City were compared in 1994. Grid sampling was better correlated in the more level landscape at Gardner than in the rolling landscape at Valley City. A 4 acre grid at Gardner was nearly as representative of 110 ft. grid NO_3-N values as a 220 ft. grid at Valley City (**Table 1**). Decreasing grid density at Valley City resulted in less boundary definition and poor field representation (**Figure 6**).

The organic matter map is a reflection of the general topography of the field at Colfax (**Figure 7**). The NO_3-N map of

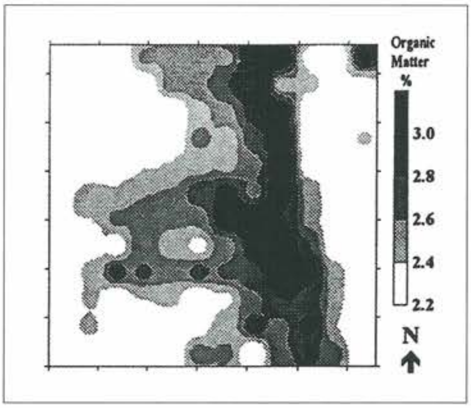


FIGURE 7. Colfax field organic matter, 1995.

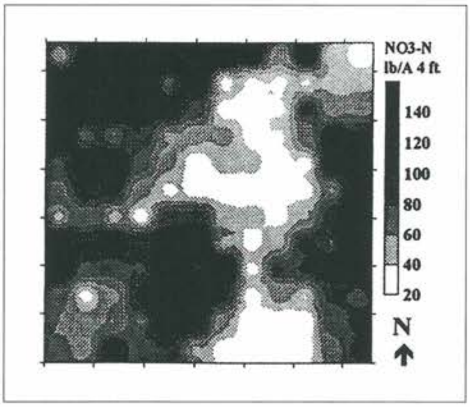


FIGURE 8. Colfax field nitrate-N to 4 ft., 1995.

Colfax (**Figure 8**) shows an inverse relationship with organic matter/topography.

Topography was measured by using laser relative elevation readings at 110 ft. intervals in the field at Mandan. Fourteen NO_3-N values were selected to represent the field for the topographic/cropping estimates. The correlation coefficient between NO_3-N sampled on a 110 to 150 ft. grid and NO_3-N sampled on a 1 to 2 acre grid was 0.290. Nitrate-N sampled by topography/cropping pattern had a correlation coefficient of 0.755 with the 110 to 150 ft. grid and showed substantial superiority over grid sampling for this field.

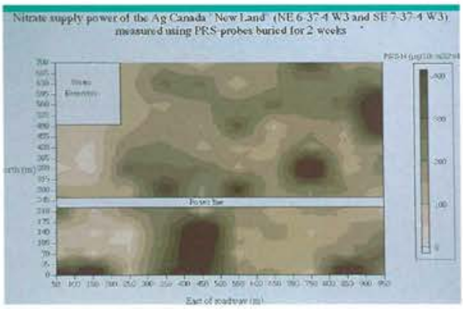
In 1996, topographic variation will be measured at all sites and more rigorous testing of the influence of topography on fertility levels will be examined. Yield monitors will be used at crop harvest at Mandan and Colfax. The profitability of site-specific sampling and fertilizer application will be explored at two of the sites.

Summary

The initial results of these studies indicate topography may play an important part in soil sampling for variable-rate fertilizer application. More research is needed to verify the preliminary observations. BC

Dr. Franzen, Dr. Hofman and Dr. Cihacek are with North Dakota State University, Fargo. Dr. Halvorson is with USDA-ARS Northern Great Plains Research Laboratory, Mandan.

Soil Nutrient Supply Rates...(continued from page 13)



MAP shows nitrate supply rate for a 150 acre field near Saskatoon.

for a 150 acre field near Saskatoon, Sask. A grid was laid out with 104 measurement points, and the PRS burial and retrieval carried out as described previously. The nitrate, phosphate and sulfate adsorbed on anion exchange probes over a two week burial were used to calculate potential nutrient supply rate differences within the field. The values were then entered into Rockware™ on an Apple Macintosh computer.

Variations in nutrient supply rate across the field revealed the expected differences related to topography and management effects. Low-lying areas of the field, where eroded soil had accumulated and organic matter and soil moisture are higher, showed the expected higher nutrient supply rates than eroded upslope areas. The influence of past management was also evident in a portion of the field revealing high nitrate and sulfate supply rates related to the fact it was previously in grass and only recently brought under cultivation.

Because it eliminates the need to collect, handle and process many soil samples while providing a unique indication of nutrient supplying power under field conditions, we believe the PRS method is a potentially valuable tool in field fertility mapping for site-specific fertility management. BC

Dr. Schoenau is Research Scientist and Adjunct Professor and Mr. Greer is Research Officer, Dept. of Soil Science, University of Saskatchewan.

NEBRASKA

Aerial Photography as an Aid in Soil Sampling

By Tracy M. Blackmer and James S. Schepers

The technology to vary fertilizer application has progressed faster than the means of obtaining an accurate prescription map economically. Economic methods that can help group regions of similar soils and direct more efficient or "smart" soil sampling strategies will increase adoption of variable-rate application technology (VRAT).

Nebraska research is showing how remote sensing tools such as aerial photography can increase the accuracy and cost effectiveness of soil sampling approaches for variable-rate fertilization. The study also shows how a composite soil sample from a variable area can underestimate phosphorus (P) fertilizer needs.

At the University of Nebraska VRAT site located near Shelton, the concept of using remote sensing to help guide better sampling practices is being evaluated. The site is a 160 acre pivot-irrigated continuous corn field that is made up of silt loam soils in the Central Platte River Valley. From this field, grid soil samples were collected on an alternate 40 by 80 ft. grid in zero to 8 in. and 8 to 36 in. increments. More than 2,000 soil samples were used to accurately map the fertility of the field.

Organic Matter

Soil organic matter was measured on the samples because it is part of the algorithm for calculating nitrogen (N) requirements and because organic matter is a good indicator of variability in many other soil parameters. The organic matter levels of the samples ranged from 1 to 5 percent and once mapped revealed a substantial spatial pattern (**Figure 1, left**).

Phosphorus

Bray P-1 soil test levels were also extremely variable, ranging from one part per million (ppm) to over 350 ppm. The average P soil test for the field was over 15 ppm and would have resulted in a zero P fertilizer recommendation using standard university guidelines in Nebraska. However, approximately 75 percent of the field tested 15 ppm or below (low or very low) and would have benefited from receiving P fertilizer. This field serves as an example of how mixing samples of low P with a few samples of very high P can result in a composite sample indicating adequate P.

The spatial pattern of soil test P was primarily associated with two factors . . . field history and soil organic matter level (**Figure 1, right**). The southwest portion of the field was influenced by an old homestead which had not had livestock present for over 30 years, but still had P levels as high as 376 ppm. In addition, the map illustrates the same spatial pattern observed in the organic matter map.

Aerial Photographs

Aerial photographs were obtained after ridge-till planting using regular 35 mm color film from an altitude of 5,000 feet. From these photographs, clear patterns of soil variability exist (**Figure 2**). The darker regions of the photograph match those regions higher in organic matter. Likewise, a similar relationship exists with soil organic matter and soil P. From this one field, it would seem that identification of areas low in P could be done by sampling a few areas of the field that are lighter in the photograph. Using a photograph to guide soil sampling for P in this field increases the chances of successfully finding deficient portions of the field with reduced soil sampling. However, if we were to apply different amounts of P to the field, this relationship would no longer be valid.

For the organic matter, it is possible to digitize the color photograph and collect a few samples from each brightness category and use those to generate an estimated organic matter map. One obstacle with generating an estimated organic matter map is the planter pattern in the image. Side-by-side passes through the field (east-west direction) vary in brightness almost as much as the color of the general regions changing in organic matter content.

Our recommendation is that pictures of bare soil color should not be taken immediately after tillage because soil moisture content has a strong influence on color. We feel it is better to wait until after the first rain because that permits the rain to stabilize the soil surface (wash the soil off the residues and allows the soil particles to form a blended color). The soil needs to dry a little after precipitation before taking the picture because some drying will embellish the contrast (the low areas will remain wetter longer and low organic matter areas will dry quicker).

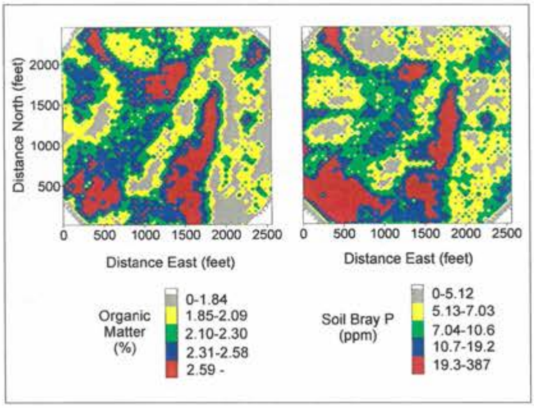


Figure 1. Over 2,000 soil samples were used to generate these maps of the levels of soil organic matter and soil test P in this quarter section in Nebraska.

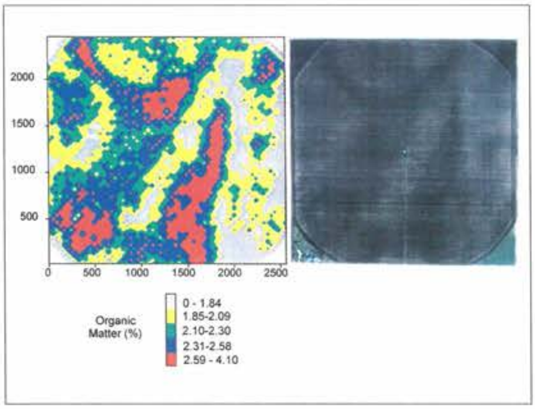


Figure 2. Note the similarity in spatial pattern of soil organic matter level and the spatial pattern of soil color from an aerial photograph.

In **Figure 2**, the image was taken the day after planting. The tillage system was ridge-till (12-row). The direction of planting affected residue orientation, which in turn influences reflectance patterns. The thing to note is that with ridge-tillage, the planter is only shaving off the top of the ridge, but the shape of the ridge affects

(continued on page 23)

ONTARIO

Delta Yield: Mapping Fertilizer Nitrogen Requirement for Crops

By R.G. Kachanoski, I.P. O'Halloran, D. Aspinall and P. Von Bertoldi

Predicting the most profitable amount of nitrogen (N) to apply at any given location in a field is the key component to a site-specific N management system. We describe a novel approach developed to obtain this information and the current testing of this approach in a large, provincial on-farm demonstration project.

Significant within-field variability of soil fertility has been well documented. In an attempt to deal with field scale variability, interest has increased in site-specific crop management systems which attempt to manage different areas within a field to their optimum. The availability of on-the-go yield monitors, variable-rate fertilizer applicators and differential global positioning systems (GPS) has given producers the technological ability to carry out a site-specific fertilizer management program. However, a critical component of site-specific N management systems is the creation of the management map which indicates how to alter the rate of fertilizer applied at different locations within the field. The task is to determine what information is required to create these management maps.

Are yield maps providing adequate information?

In recent years there has been a tremendous increase in the area of land for which geo-referenced crop yields have been collected. For the most part, the information collected displays yield variations within a field for which a constant management practice or crop input has been applied. Is this information useful for making management decisions, such as the most economic rate of fertilizer N (MERN) to apply to a given area in a field?

Information collected from over 300 fertilizer N response field trials with corn, conducted in southern Ontario during the period of 1962 to 1992, indicated that yield responses to fertilizer N application followed a quadratic relationship ($Yield = A + BN - CN^2$, where N was the amount of fertilizer N applied and A, B and C are regression coefficients). From these data sets it was observed that maximum yield and economic yield were highly correlated to each other ($r>0.94$). However, correlations with MERN indicated that only 0.7 to 10.3 percent and 0.1 to 15.0 percent of the variability in MERN was accounted for by maximum yield and economic yield, respectively. There was no significant relationship between the actual yield measured and the N required for an economic response.

Therefore, collection of yield data based on a single application rate does not give enough information for the producer to make a management decision in terms of variable fertilizer application. On-the-go

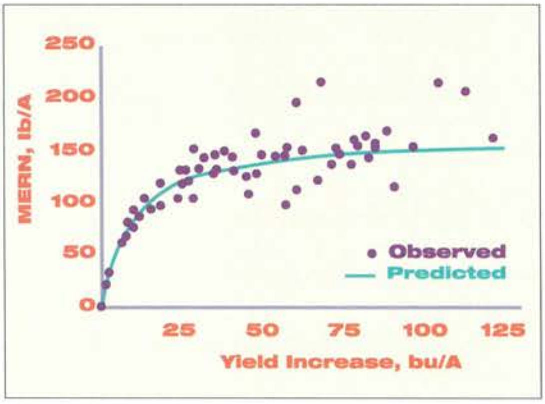


FIGURE 1. Relationship of maximum economic yield increase (ΔYield) and maximum economic N rate (MERN) for corn in southwestern Ontario. Data from side-dress fertilizer response trials conducted from 1962-1992.

yield monitor data will be of little utility in creating management maps to predict fertilizer application rates without a yield index that relates strongly to most economic fertilizer rates.

Delta Yield (ΔYield): An Index for Predicting MERN

In the context of evaluating the yield response of a crop to the application of N fertilizer, the delta yield (ΔYield) can be thought of as the increase in yield brought about by the application of N fertilizer (i.e. ΔYield = Yield with fertilizer applied - Yield without fertilizer applied). In the aforementioned Ontario studies, each field site included a zero N check treatment, and therefore a ΔYield based on either the difference between the maximum yield and the check (ΔYield-max) or the difference between economic yield and the check (ΔYield-econ) can be calculated. Correlations of MERN indicated that 50 to 77 percent and 50 to 75 percent of the variability of MERN can be accounted for by changes in ΔYield-max and ΔYield-econ, respectively. Thus, ΔYield-max and ΔYield-econ could be reasonable predictive indexes of the MERN.

Further examination of the Ontario data also indicated that the B and C coefficients in the regression equation were highly correlated to one another. The significance of this relationship (which holds across two historic data sets and three geographic locations in Ontario) is that with the ΔYield, we need only two rates of N fertilization to predict MERN where typically three or more are required.

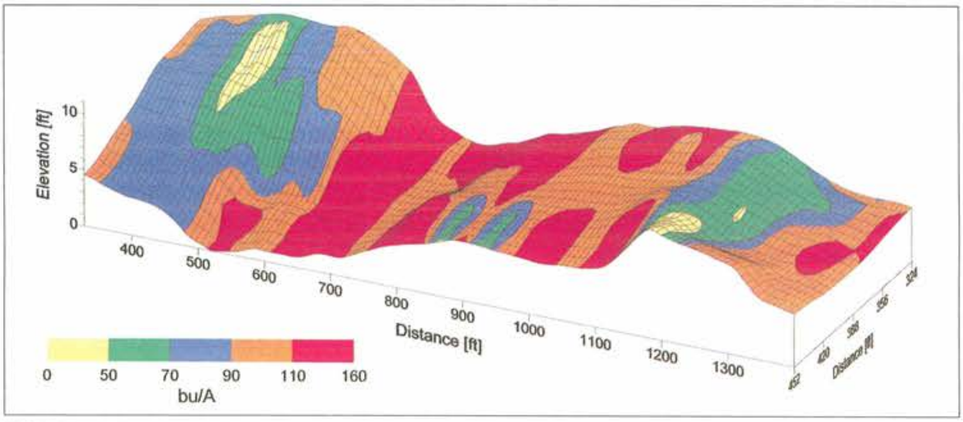


FIGURE 2. Topography and spatial distribution of yield within a 4-acre portion of a corn field fertilized at 135 lb/A of N. (Londesboro, Ontario)

Figure 1 shows the relationship between ΔYield-econ and observed or predicted (from ΔYield) MERN for sidedress N application in southwestern Ontario during 1962-1992.

Use of ΔYield in Site-Specific N Management

The usefulness of the ΔYield index in a site-specific N management system will depend on how well it can predict the spatial patterns of MERN within fields. In an initial field trial, two corn fields were divided into strips 20 ft. wide which ran the complete length of the field and received either 0 or 135 lb/A of N. Yields were estimated by both hand harvesting and combine harvesting with a yield monitor.

Landscape position had a fairly strong influence on crop yields (**Figures 2 and 3**) and on ΔYield (**Figure 4**). Note that in this field, non-responsive areas (low ΔYields) occurred both along knolls and in depressional areas, which respectively represent the lowest and highest yielding sections of the field. This further demonstrates the inability of an absolute yield map to predict the MERN. Approximately 20 percent of the field showed no response to applied fertilizer N. The most profitable response to applied fertilizer N occurred in the backslope positions. Based on the relationship given in **Figure 1** and the ΔYield map in **Figure 4**, a fertilizer recommendation map can be generated for the whole field.

Current Research

We are working on a method which may allow the producer to utilize the ΔYield approach with a minimal amount of yield loss due to the inclusion of zero N strips in the field. Ideally, one would like to be able to relate a ΔYield value to other factors which can be easily measured over the whole field. A large five-year province-wide study is underway in which 25 farm co-operators, Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) personnel and researchers at the University of Guelph are developing relationships between measurable landscape and soil attributes and ΔYield. Landscape attributes will include information derived from a digital elevation model based on data collected using high-resolution (sub-inch precision) GPS. Soil attributes will include remote sensing data.

At each site, three field-length check strips (zero fertilizer N applied) are oriented

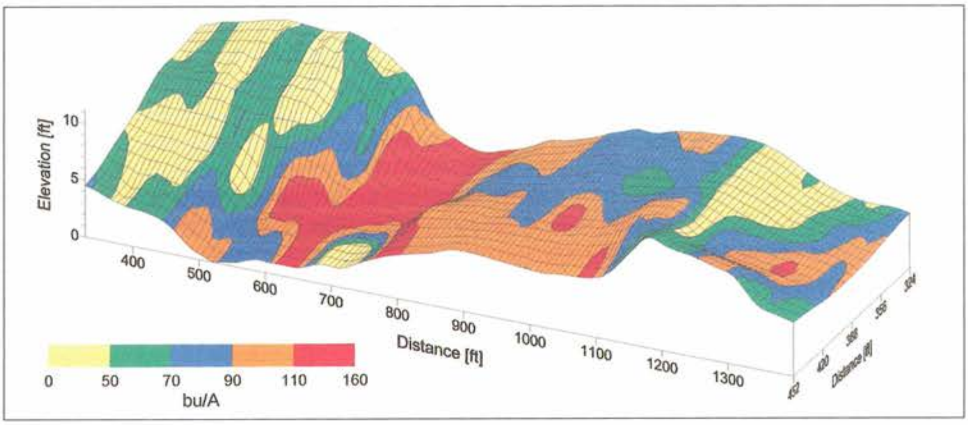
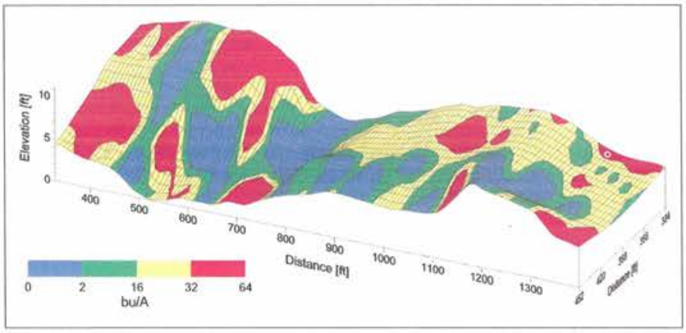


FIGURE 3. Topography and spatial distribution of yield within a 4-acre portion of a corn field fertilized at 0 lb/A of N. (Londesboro, Ontario)

FIGURE 4. Topography and spatial distribution of ΔYield within a 4-acre portion of a corn field. (Londesboro, Ontario)



to capture the variability in topography. On-the-go yield monitors with GPS generate yield maps of both check strips and areas fertilized to current recommended levels, from which ΔYield maps are derived. Relationships among landscape/soil attributes and ΔYield maps will be used to develop site-specific management maps for fertilizer N.

The next step in the project is to evaluate the management maps by comparing yields from strips receiving variably applied N fertilizer based on the management map to yields from strips fertilized at a constant recommended rate. Economic analysis of the two systems will be conducted to evaluate the potential savings and net cost/benefit associated with the variable rate system. At selected sites, more detailed studies will be conducted to examine cumulative long-term effects of site-specific N management on soil fertility, movement of fertilizer into the groundwater, and crop N uptake.

Dr. Kachanoski is Professor and Head, Dr. O'Halloran is Research Professor, and Mr. Von Bertoldi is Research Assistant, Dept. of Land Resource Science, University of Guelph, ON, Canada, N1G 2W1. Mr. Aspinall is Resource Management Specialist, OMAFRA, 52 Royal Road, Guelph, ON, Canada, N1H 6N1.

***Acknowledgments:** The authors acknowledge the contributions of the farm co-operators, and funding provided by Agriculture and Agri-Food Canada through Green Plan, OMAFRA, and the Natural Sciences and Engineering Research Council of Canada.*

Aerial Photography... *(continued from page 19)*

how much bare soil is exposed. The more soil that is removed (i.e. deeper), the wetter the soil and the darker the color. Row-to-row variation can be substantial depending on uniformity of the ridge forming process the previous year and ridge modification caused by harvesting equipment.

By waiting until after the first rain, the soil water content has a chance to stabilize and then be rather uniformly re-wetted. When soil is saturated, color differences are not as great as after a little drying.

Overall, we can use aerial photographs to help identify areas of a field that are likely to vary in certain soil properties. Caution should be employed to ensure that past management of the field or other factors have not negated the intended relationship. But if these relationships exist in other fields, it has the potential to provide a high resolution information layer at a potentially affordable price.

Dr. Blackmer is Soil Scientist and Dr. Schepers is Research Leader with the United States Department of Agriculture - Agricultural Research Service at the University of Nebraska, Lincoln.

ARKANSAS

Assessment of Rice Yield and Fertility Using Site-Specific Technologies

By W.H. Baker and S.D. Carroll

Considerable yield variability occurs in many rice fields in the Midsouth area of the U.S. If field variability can be reasonably illustrated, then decisions could be formulated to improve management in the areas exhibiting suboptimal production. The key is to begin to identify and better comprehend the factors and conditions causing this variability. Recent advances in navigation systems, yield sensors, and data analysis software have dramatically increased the effectiveness of collecting field production information. The combined result of these tools is to allow production decisions to shift from field-sized areas to much smaller units. Subsequently, the uncertainty and error associated with large block decisions are also reduced.

This investigation was designed to assess the value of using global positioning system (GPS) and geographic information system (GIS) technologies to determine field production variability. The objective was to assess the differences between site-specific yield and soil information compared to field average or composite information.

Arkansas research is providing an understanding of the value of yield monitors and intensive soil sampling in rice management.

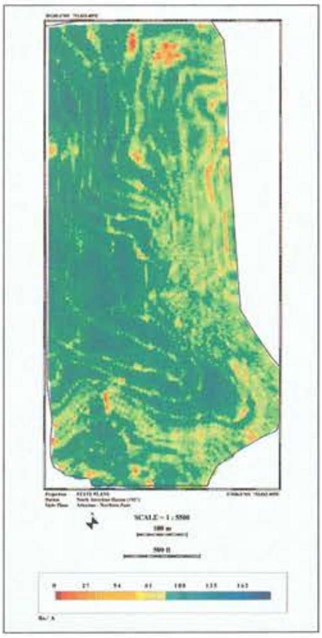


Figure 1. Continuous surface map of the yield monitoring information.

Arkansas Study

Yield information was generated using an AL2000 yield monitor coupled to a GPS receiver using the U.S. Coast Guard for differential correction. This equipment was placed on a Case IH 2188 combine. Soil test data were collected on a 2.5 acre grid using a differential GPS receiver to locate the cell centers. Each sample point consisted of a composite of five cores collected from the top 6 inches of soil on a 30 ft. radius around the center of the cell. Soil pH was measured on a 2:1 water to soil basis. Mehlich 3 extractable soil potassium (K) and phosphorus (P) were determined by ICP emission spectroscopy. The GIS used to assess the yield and soil test data was the professional version of the Rockwell Vision System software. Yield and soil test maps are presented as continuous surfaces derived from an inverse distance model. These surfaces are analogous to contour intervals. The farm production system investigated was a rice and soybean rotation located on a clay pan silt loam soil in the mid-Arkansas Delta region. Eight soybean and rice fields consisting of 1,200 acres were yield monitored and grid soil sampled. The data discussed in this article were from one of these fields (110 acres), that had been cropped to rice for the last three years.

Production Observations Based on Yield Monitoring

The yields from some of the first fields to be harvested were disappointingly low. This field was no exception. The yield ranged from 20 to 139 bu/A with an average yield of 32 bu/A, nearly 35 bu/A off the expected yield.

Yield monitoring data are presented in **Figure 1**. One interesting feature observed from this surface map is the appearance of the levees at the lower end of the production scale. The yield data indicated nearly 40 percent of the field was below the mean of 32 bu/A. This low production level was largely associated with one end of the field that was poorly drained. Some seedling stress probably occurred from early season cold and wet weather. A large strip of this low yielding area had been filled and the fill material may have restricted soil drainage. Clearly, a soil physical problem was associated with the low yielding areas in this field.

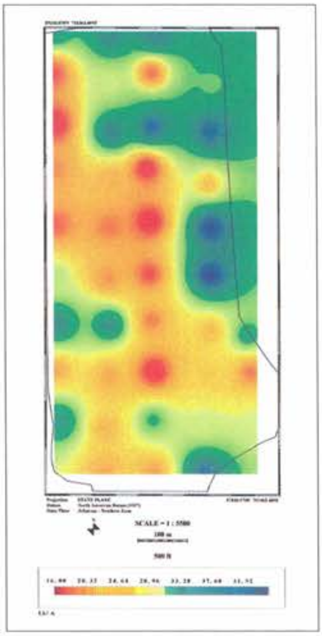


Figure 2. Continuous surface map of the grid sampled soil test P information.

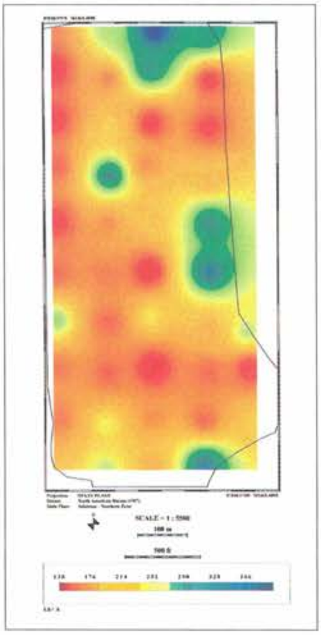


Figure 3. Continuous surface map of the grid sampled soil test K information.

Soil P and K Fertility Assessment

The field composite soil sample represented the average of all 42 of the soil test values from the grid soil samples. Under normal circumstances, a field of this size and appearance would be divided in half and characterized based on two composite samples. Approximately 53 percent of the field was below the mean P value of 28 lb/A, shown in **Figure 2**. The field average, or composite, for soil test P just missed a rice recommendation for P fertilizer based on the current critical level of 25 lb P/A. A large fraction of the low P soil area corresponded to the area where yield monitoring indicated the field was most productive.

The results for soil test K indicated a mean value of 215 lb K/A. The range in these data was from 139 to 400 lb K/A. While the mean soil test was above the critical level of 175 lb K/A for rice, this field

(continued on page 29)

ILLINOIS

Use Caution in Interpreting Clusters of Similar Values in Soil Fertility Maps

By Linda Anderson and Don Bullock

Global positioning satellites and associated technology have made variable rate technology (VRT) applications of fertilizer easier to perform. We can accurately record locations of data gathered from fields and then differentially treat areas of those fields. When correctly used, VRT increases fertilizer efficiency. The fertilizer is applied where it is needed and at the proper rate.

Illinois researchers use a simulation to demonstrate that clusters of similar values in a map don't automatically indicate the map is accurate.

An accurate map is needed for VRT fertilizer application. The map must indicate the real varying fertility levels of the field. Experience has taught us that this is much easier said than done and that in fact many maps used currently probably are not accurate and do not portray the actual fertility levels of the fields they represent. We are not suggesting that VRT does not work. Rather we are suggesting that if VRT is to work, then accurate maps must be produced.

To collect information for fertility maps, soil samples are collected – usually on some regular grid interval. In Illinois and much of the central Midwest this is a 330 ft. grid (2.5 acres). Maps are then produced with an implicit assumption that point samples from adjacent areas are representative of those areas and/or are correlated to adjacent and nearby sample points. It is assumed that when several samples of similar value (e.g. low Bray P-1 test) are clustered together in an area, that portion of the field has a low Bray P-1 value. The assumption may or may not be true. Certainly a cautious approach is warranted.

It should be understood that for any given field, similar soil samples can cluster together randomly and not be indicative of uniformity in a particular area of the field. For example, if two copies of the numbers one through fifty (100 pieces of paper) were put into a hat and drawn out one at a time, it would not be surprising if one were occasionally to sequentially draw out from the hat several numbers that are numerically similar (e.g., 46, 48, and 53). The problem is made even worse because most individuals will categorize such quantitative results into a small number of discrete intervals such as low, medium, and high. This results in an almost certain occurrence of a clustering of categories. Again it should be stressed that in this case the clustering would not be indicative of a true fertility area in the field. Rather it is a random, but anticipated, clustering.

An Example

Although taking soil tests is not drawing numbers from a hat, we performed a soil test simulation in the spirit of drawing numbers. Using the distribution (lognormal), mean (61.5), and variance (927) of an actual 80 acre research field, we produced a random data set on a 20 ft. grid (8,192 points) for a Bray P-1 test. Note that in this case the samples were generated randomly and are not correlated. Thus, the value of any given point gives absolutely no information regarding the value of an adjacent or nearby point. We then came back into this random data set and simulated the current standard 330 ft. (2.5 acre) sampling grid (**Figure 1**) and a 165 ft. (0.65 acre) sample grid (**Figure 2**). Clustering of varying fertility categories is evident in both. The clusters are indicative of nothing other than a random event.

It is critical to understand two major issues. First, the single measure for a given block, either the 2.5 acre (**Figure 1**) or the 0.65 acre (**Figure 2**) is not representative of the entire block although many would assume it to be. Second, the information obtained from a single point sample tells us nothing about nearby points. This second critical issue is absolutely true for this data set because it is random, but it is also true for actual field data if the sampling grid results in uncorrelated samples because they were taken at a distance greater than the range of correlation.

The range of correlation can and should be tested with geostatistical techniques, but commonly is not tested. Rather, an inverse distance interpolation is performed by most mapping programs and this assumes that real samples are correlated and that a weighted average of surrounding samples can be used to estimate any point that is not sampled.

This technique assumes that the similarity of points depends on the distance that separates them. Thus, the weights are proportional to the inverse of the distance (1/d), and the samples that are farther away are given less weight individually. Inverse distance squared ($1/d^2$), cubed ($1/d^3$), and to the fourth power ($1/d^4$), are also used. In these cases, distant samples are given even less weight than in inverse

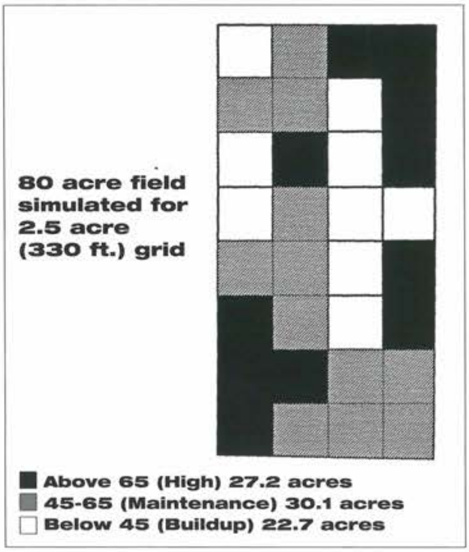


FIGURE 1. Field simulation of soil test P distribution using random numbers, 330 ft. grid.

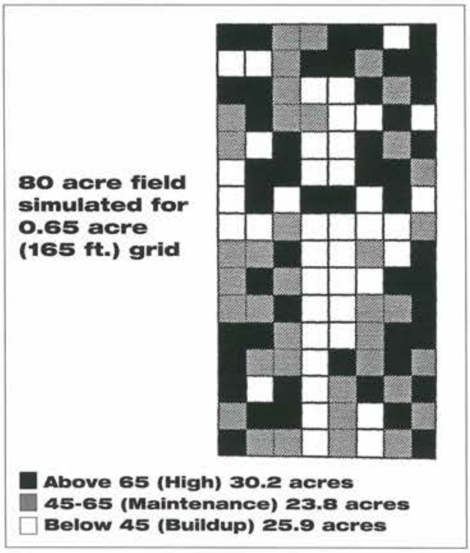


FIGURE 2. Field simulation of soil test P distribution using random numbers, 165 ft. grid.

distance, and the nearest samples are given most of the weight.

For example, given a 100 ft. interval, and a point to be estimated halfway between two samples, the closest samples would have weights proportional to 1/50, and the next 1/150, if inverse distance (1/d) is used. If $1/d^2$ is used, the weights would be proportional to $1/50^2$ (1/2,500) and $1/150^2$ (1/22,500). Thus, with inverse distance, the nearer samples would be weighted three times more than the farther samples. With inverse distance squared, the weights would be nine times greater, with inverse distance cubed, twenty-seven times greater. For $1/d^3$ or $1/d^4$, only the very nearest points are included in the estimate. This has the effect of simply drawing lines around all areas of similar soil test values. If the field is highly variable, very small areas are defined. Additionally, current algorithms will consider issues such as the number of neighbors and/or a minimum distance.

We used such a technique with the results of our generated random data set to produce soil fertility maps of the 330 ft. grid (1/d) (**Figure 3**); 165 ft. grid (1/d) (**Figure 4**) and 165 ft. grid ($1/d^3$) (**Figure 5**). The first two examples using the inverse distance produced convincing, if not similar maps. The last example, using the inverse distance cubed, produced a seemingly overly detailed map.

While the first two maps, in particular, look reasonable and fit well with our expectations for soil fertility variation, they are not correct and represent nothing other than a random clustering of values and the ingenuity of the programmers that developed the mapping software. We should note that such an endeavor predicts certain values for non-sampled points based on nearby points, but in fact the predictions are worthless in this case. If a nonsampled point does fall into the predicted category it is simply by chance.

Summary

We are not suggesting that VRT will not or does not work for fertilizer application. We believe sincerely that VRT can work and has much to contribute to the improvement of fertilizer use efficiency. VRT must have an accurate map, however, and that map must be based upon a

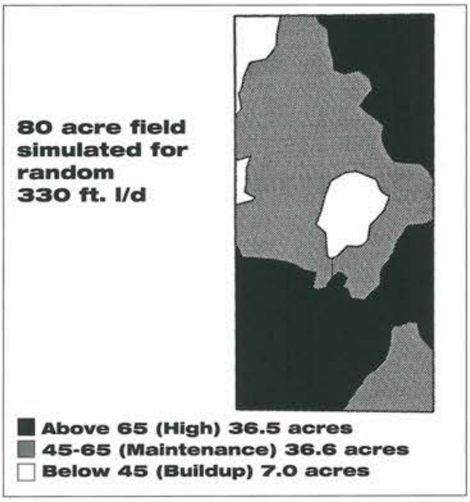


FIGURE 3. Field simulation of soil test P distribution, 330 ft. grid, inverse distance weighting.

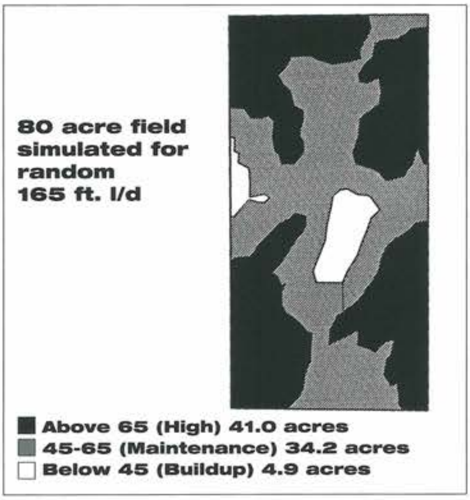
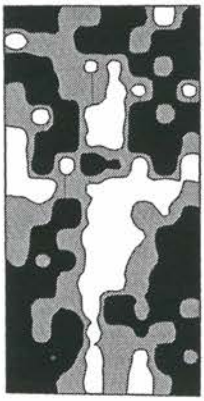


FIGURE 4. Field simulation of soil test P distribution, 165 ft. grid, inverse distance weighting.

sampling density which includes distances at which samples are correlated. We wish we could provide guidance to the required sampling density for all fields, but we and others are still researching that question. We have seen cases where it appears that 2.5 acre samples will work, but we have also seen many cases where a far more dense sampling regime must be used. We strongly argue that all fields be given more rigorous geostatistical consideration. We also believe that the best way to make VRT fertilizer application decisions for many fields is to base those decisions upon previous yield maps and nutrient removal calculations.

Linda Anderson is Research Specialist and Dr. Bullock is Associate Professor of Agronomy and Biometry, Biometry Group, Dept. of Crop Sciences, University of Illinois, Urbana, IL.

80 acre field simulated for random 165 ft. I/d^3



- Above 65 (High) 35.3 acres
- 45-65 (Maintenance) 27.0 acres
- Below 45 (Buildup) 17.6 acres

FIGURE 5. Field simulation of soil test P distribution, inverse distance cubed weighting.

Rice Yield... *(continued from page 25)*

would require a moderate addition of K fertilizer based on a composite sample assessment. However, the surface map of soil test K, **Figure 3**, was even more revealing. A large part of the field was shown to have K values at or below the critical level. The grid soil sampling and GIS evaluation plainly illustrated a compelling need for adequate K fertilization.

Summary

Rice production was almost certainly limited by P and K fertility as indicated by yield monitoring and soil test data. The most limited areas of P and K availability corresponded with the high yielding areas. Evidently, larger amounts of soil P and K were being removed where yields were placing the greatest demand. Rice in the less-demanding low-yielding areas was probably restricted by poor soil physical conditions and was not found to be limited by fertility considerations.

The combination of site-specific yield and soil sampling data provided a significant improvement in the quality of information available to make production assessments. While the expense of generating these types of site-specific data is significant, the increased insight and number of yield-improving options offer great promise.

Dr. Baker is Research Assistant Professor and S. D. Carroll is Research Specialist, University of Arkansas Soil Testing and Research Laboratory, P.O. Drawer 767, Marianna, AR 72360.

Acknowledgment: *The authors wish to express their appreciation and recognize the investigative contribution, equipment use, and support by Archie Mason of Pro Ag Services located in Wynne, AR.*

MINNESOTA

Grid Soil Testing and Variable-Rate Fertilization for Profitable Sugarbeet Production

By Larry J. Smith and Doug Rains

Grid sampling should identify variability in nutrient status. Coupled with variable-rate fertilization, it should provide the crop with optimum fertility during the season, yet not waste fertilizer on areas of excess or adequate nutrients. Of particular importance to sugarbeet quality is excess available nitrogen (N), especially below 2 ft. deep in the soil profile.

A study conducted jointly by university and industry shows why the Red River Valley of the North has become a hot bed of precision agriculture activity.

Red River Valley Study

There were several objectives of this study. 1) Determine the variability in nitrate-nitrogen (NO_3-N) levels at depths of 0 to 4 ft. across the field used in commercial sugarbeet production. 2) Use grid soil sampling to ascertain if variable rate application of fertilizer corresponding to grid soil sampling versus random soil sampling in broadcast fertilization will increase yield, quality and profitability. 3) Follow the nutrient status of the field in years following sugarbeets to determine if, how and why variability in nutrient status changes.

This study was conducted at the Northwest Experiment Station at the University of Minnesota in a 62 acre field in 1994 and a 70 acre field in 1995. The fields were in a 4-year sugarbeet rotation (sugarbeet, wheat, corn, barley) and were conventionally and grid soil sampled in mid-October to determine nutrient status. Headlands were not included in either sampling or used in the trial. Nitrate-N status was determined at the 0 to 6 inch, 6 to 24 inch and 24 to 48 inch depths. Phosphorus (P) and potassium (K) were determined on the 0 to 6 inch sample. Conventional sampling consisted of 30 to 40 probes in a random pattern throughout the field. Grid size was 370 x 359 ft. (3 acres) in 1994 and 566 x 212 feet. (2.8 acres) in 1995. Each block was sampled six times.

TABLE 1. Summary of available soil NO_3-N levels and fertilizer recommendations from 1994 and 1995 locations.

		N, lb/A[1]	
Factor		1994	1995
Available soil NO_3-N from conventional sampling		95	83
Average available soil NO_3-N from grid sampling		81	76
Range in available soil NO_3-N from grid sampling		21-180	39-102
Conventional N recommendation		25	37
Variable rate N recommendation:	Average	63	78
	Range	0-100	26-100
% of field underfertilized using conventional sampling		65	79

[1]NO_3-N from 0 to 2 ft + 80% of the NO_3-N in the 2 to 4 ft increment that exceeds 30 lb/A.

TABLE 2. Sugarbeet yield, quality and gross returns.

Factor	1994 Location		1995 Location		2-year average	
	Conv.	Variable	Conv.	Variable	Conv.	Variable
Yield, tons/A	24.3	25.5	22.9	23.9	23.6	24.7
Recoverable sucrose, lb/ton	287	296	286	293	287	295
Recoverable sucrose, lb/A	6,982	7,555	6,542	6,976	6,762	7,266
Gross return, $/A	898	994	848	921	873	958

The fields were divided into four strips with two receiving a blanket broadcast application of N based on the conventional soil test and two being variable rate-fertilized based on the grid test results. The trial was designed to look only at N fertilization. A broadcast application of 46 lb/A of P_2O_5 was made to the entire field to insure adequate P availability.

The study was harvested using conventional field equipment. Each of over 100 truck loads was weighed and two samples removed for sugar analysis.

The Results

Grid soil sampling gave a far more accurate estimation of available soil N in the 0 to 4 ft. profile than did conventional sampling (**Table 1**). Substantial areas were under-fertilized each year using conventional sampling and the resulting single fertilizer rate for the entire field.

Variable rate fertilization out performed the conventional methods of soil testing and fertilization in both years of the study (**Table 2**). Both yield and sugar content were higher for the variable rate treatment leading to an average increase in gross return of $85/per acre. Additional costs incurred by the variable rate approach from sampling, testing, application, and extra fertilizer totaled $25/per acre, leaving an average net return to variable rate N of $60/per acre (**Table 3**). These are actual costs being charged for this region and will vary with field, grid size and company.

Summary

Grid sampling and variable rate fertilization are tools that will hopefully improve the sugarbeet grower's bottom line. Variable rate fertilization of fields with excessively high NO_3-N in the 2 to 4 ft. soil profile over the majority of the field probably will not improve sugar content or reduce loss to molasses. Grid sampling will give a better picture of where excess soil NO_3-N levels exist and, if used correctly, may help reduce the levels before sugarbeets are again planted in a particular field. BC

Dr. Smith is Agronomist, Northwest Experiment Station, University of Minnesota, Crookston, Minn. and Mr. Rains is Agricultural Superintendent, American Crystal Sugar Company, Crookston, Minn.

TABLE 3. Profit analysis for two years of variable rate N for sugarbeets.

Factor	Conventional	Variable	Difference (Var.-Conv.)
Gross return, $/A	$873.00	$958.00	+$85.00
Soil sampling and testing, $/A	0.70	12.80	-12.00
Fertilizer application, $/A	3.50	8.50	-5.00
Fertilizer N costs, $/A	6.20	14.10	-8.00
Net return to variable rate N, $/A	863.00	923.00	+60.00

CALIFORNIA

Computer Enhancement of Aerial Photographs

By Mike Porter

The application of geostatistics aids in interpolating between sampling sites, reducing the number of samples needed to provide a given level of area-specific knowledge. But, in the end, geostatistical approaches are still limited by fundamental mathematical considerations...the greater the variability of the soil, the more samples that need to be taken to achieve any given level of mapping accuracy.

Perhaps the simplest way to overcome the sampling density limitation is to have such a high information density that statistical methods are redundant. That is, instead of starting with field samples then calculating a best-estimate map, start with the map and use it to decide where to take samples. One might wonder where you get the map... the fact is you get it from the foliage. What sampling strategy could provide the density of information provided by thousands or millions of plants individually testing the soil? The trick is to extract the information quickly and easily.

Soil variability has long been known to complicate the task of efficient fertilization. Mapping soil accurately is an important aid in deciding nutrient needs, application rates and where to apply. Soil and tissue sampling helps considerably but are limited by sampling density. That is, too few samples provide too little information, but a sufficient number of samples can cut into profitability. Aerial photography can be utilized to map vineyard soils and plant nutrition quickly and easily.

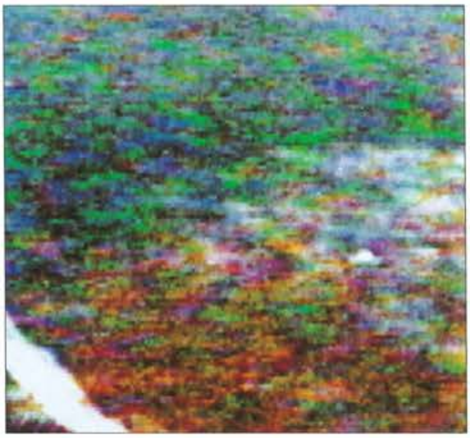
This is not a new approach, of course. This is what aerial photography has been used for since Gaspard Tournachon photographed the outskirts of Paris from a balloon in 1858...rapid mapping at a high information density. As cameras, film and aircraft have improved so has the utility and cost-effectiveness of the practice. In refining the tools and techniques, a wealth of information has flowed out to people on the ground. But, as with any technology, there are still inherent limitations.

Strengths and Weaknesses

Visual interpretation of a scene is something that people are generally quite good at, whether viewing in person or looking at a photograph. Unlike the slow linear process of reading or listening to someone speak, the eyes and mind can absorb a massive amount of information at one time. In the vernacular of computers this is called parallel processing, and to date most people are still much better at this than computers.

Research into how we do this indicates that about 70 percent of the information that we glean comes from differences in contrast, that is, how light or dark one part of a scene is from those around it. This explains how we see and can inter-

ORIGINAL, true-color photo of a 40-acre wine-grape vineyard has subtle differences, difficult to discern.



COMPUTER-ENHANCED photo shows greater contrast in wine-grape foliage, indicative of differences in soil characteristics.

pret so much from black-and-white photographs, and why color-blind people (and animals) function so effectively. Only 30 percent of the information in a scene is normally obtained from differences in color, though this can be critical when dealing with foliar symptoms of nutrient problems.

The main limitation in interpreting natural-color aerial photographs for agricultural use is that most such scenes have very little contrast and only subtle color variation. Low-contrast scenes rob us of our visual strength, and modest differences in color often slip past us. What is needed then is a way to increase the contrast in a scene and/or exaggerate the colors.

Methods and Options

Increased differences in color and contrast have been achieved, typically by trying different films and filters and by various darkroom practices. One widely-used combination is "false-color" infrared film combined with a red or deep yellow filter. This changes foliage from yellow-green to red and, more importantly, increases the contrast. Having tried various films and filters, and finding them all wanting in one way or another, the next logical step was to try enhancing contrast and color in a computer.

Computer enhancement of photographs has been around for quite a few years, but for most of that time was limited to those who had access to the fastest and most powerful computers available (NASA, FBI, CIA, NSA, etc.) because the massive amount of data involved requires great speed and available memory. In recent years the capacity of desktop personal computers has risen to the level required, and sophisticated off-the-shelf software has been developed to match.

Field Use

The photos with this article show the original, true-color and an enhanced version of the same scene of a 40-acre wine-grape vineyard in Sonoma County, California. The view is obliquely across the rows so as to see the maximum amount of foliage and the minimum amount of bare soil between rows. After studying the enhanced version, one can go back to the original and find many of the subtle dif-

(continued on page 36)

ALBERTA

Global Positioning Systems and Electromagnetic Induction – High Tech Tools for Salinity Mapping

By Colin McKenzie

Soil salinity is a major cause of reduced crop production in many soils of the northern Great Plains. Traditional methods for mapping salinity were based on a few soil samples per quarter section. Limited samples make it difficult to accurately describe the extent and variability of soil salinity and the rate of salinization.

The electromagnetic induction meter (EM38), a relatively new method for rapid measurement of salinity, has greatly improved our ability to measure soil salinity. The EM38 records conductivity readings proportionate to the amount of salts in the soil solution. And, because it does not require direct soil contact, a large number of salinity measurements can be obtained at much lower costs than by conventional sampling methods.

The EM38 salinity measurements can be made by either an operator carrying the unit on the shoulder or with the unit mounted on a non-magnetic sled pulled by a vehicle operating at speeds of 6 to 12 miles per hour. This allows about 18 to 36 acres to be surveyed per day when mapping on 33 by 130 ft. grid.

Though an improvement over conventional salinity mapping methods, use of the EM38 had some constraints: (1) establishing the grid takes considerable time, (2) movement of the EM unit along predetermined straight grid lines can be difficult in rugged topography, and (3) it is difficult to conduct more frequent measurements in local areas where salinity is suspected of changing rapidly, such as long irrigation canals. Teaming up the EM38 with GPS has removed these constraints and further improved the ability of the EM38 to document soil salinity.

New measuring techniques combined with global positioning systems (GPS) are improving the accuracy of soil salinity mapping.

Alberta Experiences

A few years ago we began testing a differential system GPS and an EM38 meter to map salinity in southern

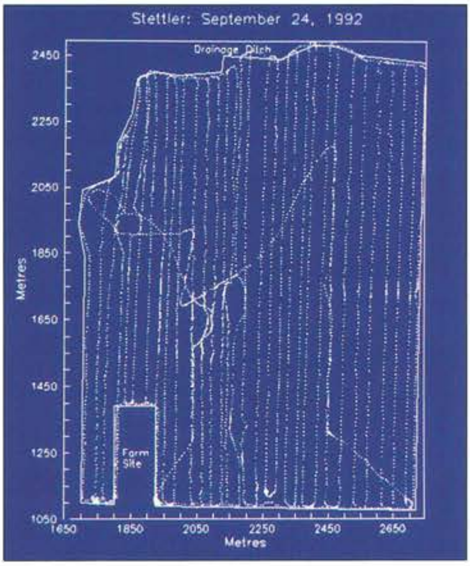


Figure 1. An EM-GPS soil salinity survey of a 120 acre field generates 6,000 data points in three hours.

Alberta. An all terrain vehicle was used to pull a non-magnetic toboggan housing the EM38 and the GPS receiver.

Results from a 120 acre field near Stettler, Alberta, are shown in **Figure 1**. The 6,000 data points were generated in three hours, confirming the high productivity of the GPS-based EM system. The random trajectories zigzagging the parallel runs were made intentionally at the end of the survey to obtain cross-over measurements for verifying the internal accuracy of the system. The salinity measurements obtained at the 51 cross-over points, located within about 40 inches of each other, and duplication of the survey on a subsequent day showed that the GPS-based EM system was repeatable and accurate.

Combining GPS and EM38 technology permits the user to easily map irregular shaped areas where rough topography, trees and buildings restrict the line of sight to ground targets. Under normal operating conditions this system can easily survey up to several hundred acres per day, which is about a five-fold increase compared to use of conventional grid EM survey methods.

Detailed and rapidly made salinity

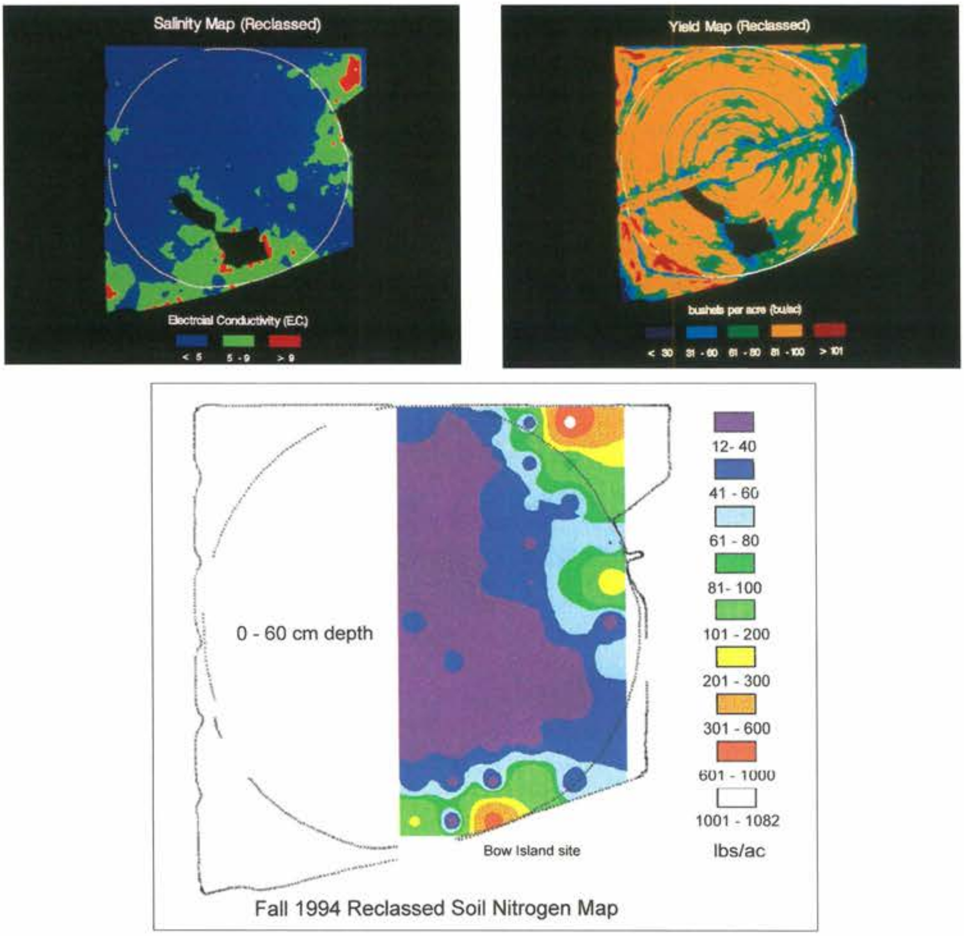


Figure 2. Salinity map derived from a GPS-based EM system, soil nitrogen map based on soil sampling and a yield map made from a yield monitor of an irrigated soft wheat field.

maps will help define the yield limitations necessary for site-specific management. **Figure 2** compares a salinity map made using a GPS-based EM system, a soil nitrogen (N) map based on intensive soil sampling, and a yield map made from a yield monitor for an irrigated soft wheat field near Bow Island, Alberta. Note areas of high electrical conductivity (i.e. salinity) correspond to areas of high N and low wheat yields.

A fertilizer recommendation based on a composite soil sample is influenced by these saline areas with high N. This causes an under-estimation of the fertilizer requirement for most of the field while unnecessary fertilizer is applied to the saline portions of the field. Salinity is easier to identify and map than is soil N.

A detailed salinity map will permit crop selection to be used as part of precision farming. For example, when growing a saline-sensitive crop like corn or beans, saline portions of the field can be planted to a more salinity-tolerant crop like barley.

Summary

Geographic information systems (GIS) allow data from yield, salinity, topography, fertility or other maps to be combined and analyzed to generate more accurate variable rate input maps. Salinity maps are one more tool in a farmer's arsenal to better utilize and manage the information needed for precision agriculture. BC

Dr. McKenzie is Research Scientist, Soil and Water, with the Alberta Agriculture, Food and Rural Development Crop Diversification Centre, Brooks.

Computer Enhancement... *continued from page 33*

ferences that were there all along, but were difficult to discern at first. The enhancement process has not created any new information, merely exaggerated what was there.

The red-orange foliage in the lower portion of the scene results from soil having very high available magnesium (Mg), high cation exchange capacity (CEC) and plants with potassium (K) deficiency. This area is a former (Pleistocene) lakebed, dominated by montmorillonitic clays. The upper green portion is an alluvial fan whose watershed is largely rhyolite, giving the soil a lower CEC and a much better K/Mg ratio. The peak of the fan is at the upper left. One can see the gradation from lighter to darker green associated with decreasing rock and gravel, increasing silt content and associated variation in soil water-holding capacity. The irregular white patch in the middle-right portion results from very weak vine growth, so that we are seeing much more bare soil than in other parts of the vineyard. This section has shallow soil underlain by a calcium-cemented hardpan.

If one were not familiar with this vineyard, it could easily require many backhoe pits and samples to "investigate" the soil in enough detail to make a geostatistical map. Using the computer-enhanced photo as a guide, it would be much simpler (and less expensive) to sample in key locations, then use the photo as the map. BC

Mr. Porter is a vineyard consultant in the North Coast region of California, located at Forestville.

ALBERTA

High Soil Variability Leads to Under-Fertilization

By Doug Penney, Tom Goddard and Terry L. Roberts

Fertilizer recommendations have been developed using small plot experiments. The resulting soil test calibrations are used in conjunction with average soil test values from fields assumed to be uniform. However, yield monitors are revealing that large variations in crop yields are common, and intensive soil sampling is showing that soil tests values in fields are highly variable. These natural variations in yield and nutrient levels provide the basis for variable rate application technology. They also are causing us to re-think some of the underlying principles upon which constant rate fertilizer recommendations are made.

Crop yield and soil test levels are two of the main factors used to predict fertilizer requirements. Yield potential or yield goal determines nutrient levels the crop needs. The soil test and an established relationship between crop response and fertilization determine how much fertilizer to apply. Other soil characteristics or climatic factors can be used to further refine the fertilizer recommendation.

Alberta Studies

Site-specific technology using a differential global positioning system (DGPS) was used to map grain yield, terrain, fertility and salinity at several locations in Alberta. The fields were distributed across diverse soils on undulating to rolling topography from central to southern Alberta. Soil nutrients were mapped using a 220 ft. x 220 ft. sampling grid.

Grid sampling showed soil nutrient levels were spatially variable, regionalized and positively skewed. When nutrient concentrations in a field are positively skewed, the mean value obtained from a composite sample over estimates the nutrient content of the majority of the field. **Figure 1** shows typical results for soil nitrate-N (NO_3-N) for an irrigated field in southern Alberta. Values ranged from 6 to 541 parts per million (ppm). The mean (42 ppm) was twice as high as the mode (20 ppm). The mode is the value, or class, that occurs most frequently in the field. In this field, areas of high NO_3-N were usually associated with high salinity and low yields.

Figure 2 shows the frequency distribution for soil test potassium (K) for a field in central Alberta. Potassium levels were variable with values ranging from 59 to 310 ppm. The mean was 135 ppm K and was 27 ppm higher than the mode. Approximately 37 percent of the gird areas sampled tested greater than 143 ppm K, and would not require K fertilization according to Alberta recommendations. Yet, 30 percent of the area was less than 101 ppm and would require K fertilization and 33 percent was between 101 and 143 ppm and may need supplemental K.

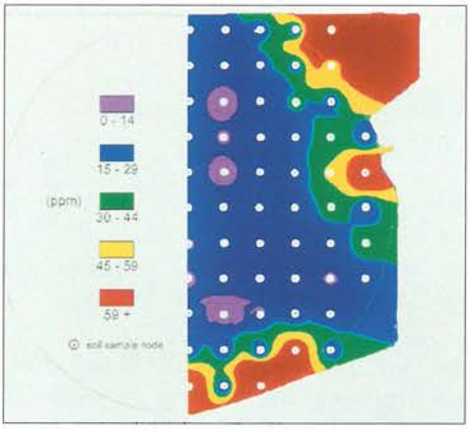


Figure 1. Spatial distribution of nitrate-N from a 220 ft. x 220 ft. sample grid irrigated field in southern Alberta (fall 1994).

Other sites in Alberta have shown similar trends of high variability and positively skewed data. **Table 1** summarizes K results from the four Alberta sites studied. In all cases, mean soil K values were substantially higher than mode values, indicating the true K status of the fields would be over-estimated by composite sampling. This same trend was observed for soil test nitrogen (N), phosphorus (P) and sulfur (S). Of the 42 data sets generated so far, the mean value has been greater than mode in all cases, except for three data sets for soil test P.

If the frequency distribution of soil test values in a field were normal, or unbiased, the mean and the mode would be equal, and both would represent the most frequent occurrence of that value in the field. However, when the mean is greater than the mode, a fertilizer recommendation based on an average value will underestimate the fertilizer required.

Positive skewness results in a systematic error when composite samples of fields are used for soil test recommendations. Small-plot experiments used for soil test calibration are usually carried out on uniform areas within the same landscape unit. The variation in soil test levels within small-plot experimental areas is unlikely to have the positive skewness shown to occur frequently in large fields. This means soil tests calibrated using small-plot trials often under estimate the optimum fertilizer rate for larger fields when the recommendations are based on composite samples of the fields. This helps explain why some fields testing high in available K, or other nutrients, still respond to fertilization.

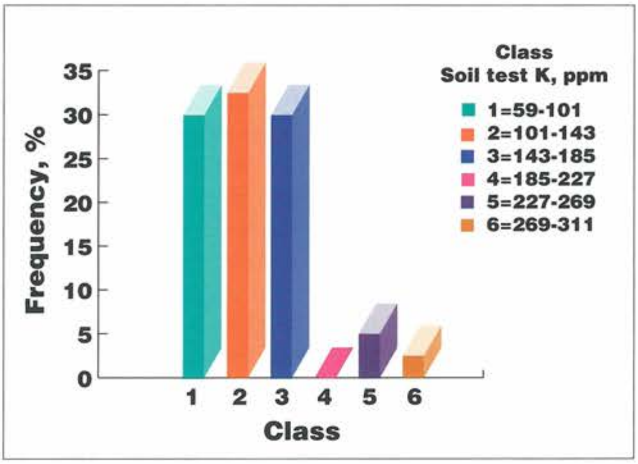


Figure 2. Frequency distribution of soil test K for a central Alberta site (fall 1993).

Summary

Spatial variability and the frequency distribution of soil nutrients have important implications for constant rate fertilizer application. Results from our work, and others, demonstrate that nutrient levels in fields are often highly variable and positively skewed. Small areas of fields with high soil test values increase the overall field average. This distorts the true fertility status of a field and can result in much of the field being under-fertilized.

Identifying the variability that occurs in fields through grid sampling and mapping specific management units are key elements of site-specific management and variable rate fertilizer application. Avoiding over fertilization in areas of high nutrient content will become an increasingly important benefit of variable rate technology. Recognition of the variability and the inherent systematic error associated with composite sampling will also allow us to better refine fertilizer recommendations for use with constant rate fertilization.

Mr. Penney and Mr. Goddard are Soil Specialists with Alberta Agriculture, Food and Rural Development, Edmonton. Dr. Roberts is PPI Western Canada Director, Saskatoon, Saskatchewan.

TABLE 1. Statistical characteristics of soil test K (ppm) from a 220 x 220 ft. sampling grid for Alberta sites.

Site	Year	Sample no.	Min.	Max.	Mean	Mode
1	1993	60	175	613	326	208
	1994	58	220	880	425	371
2	1993	59	162	604	323	260
	1994	60	165	839	410	247
3	1993	58	119	618	293	159
	1994	55	127	598	276	155
	1995	53	112	499	265	183
4	1993	40	59	310	135	108
	1994	40	84	418	177	137
	1995	40	69	414	162	129

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The Information Age

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