BETTER CROPS
WITH PLANT FOOD

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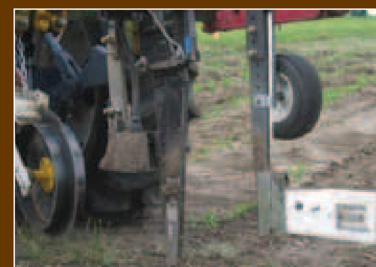

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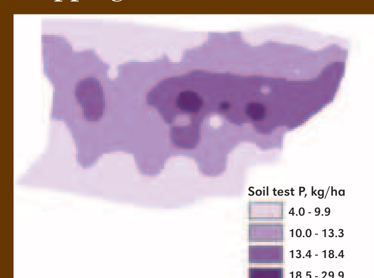

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Our cover: Testing crop sensors in alfalfa in the Ukraine.
Photo courtesy of Trimble Navigation.
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C O N T E N T S

Note to Readers: Articles which appear in this issue of *Better Crops with Plant Food* (and previous issues) can be found as PDF files at the IPNI website: **>www.ipni.net/bettercrops<**

Welcome to this Focus Issue on Spatial Variability

By Terry L. Roberts and Steve Phillips

One of the objectives of the International Plant Nutrition Institute's global working groups is to advance understanding of spatial and temporal variability in agricultural systems and the impacts on nutrient management decision-making processes. Proper understanding of spatial and temporal variability as core issues and integrating them into a nutrient recommendation system can ensure that fertilizer will be used adequately and in a balanced manner. Such a process will improve productivity and result in less environmental impact as nutrient management is varied to better match local requirements.

An international survey of agronomic scientists, industry agronomists, and growers was conducted by IPNI staff to determine the most important reasons to consider spatial and temporal variability. Some of the responses were to assist in new technology development, to improve computer simulation accuracy, and to help guide nutrient management legislation. Respondents indicated that variability management is needed to ensure the productivity and profitability of crop production. Also noted was the importance of protecting environmental resources, which can be accomplished by spatially distributing plant nutrients according to changes in need.

The unpredictability of weather and its effect on crop productivity and nutrient requirements was listed as a major challenge by most respondents. One of the most frequently cited reasons for considering spatial variability was so that nutrient recommendations can be made at the appropriate scale. The number one response was that making the right fertilizer decision depends on spatial and temporal effects at the field level. Failure to consider these factors when determining nutrient sources, rates, application timing, or placement can affect fertilizer efficiency and effectiveness. It is widely accepted that not all areas of a field respond the same to fertilizer applications. Whether the source of the variability is changes in soil physical characteristics, topography, or nutrient or water holding capacity, different yield potentials exist within a field and among similar fields. Applying a uniform nutrient rate to the entire field or farm will result in some areas receiving too little fertilizer, which results in yield loss, and some areas receiving too much fertilizer, which is a concern both economically and environmentally.

This issue of *Better Crops with Plant Food* is dedicated to articles focused on research being conducted around the world to address and account for spatial and temporal issues

when managing plant nutrients. From large scale operations in North and South America to small land-holdings in China and India, growers face spatial and temporal challenges in crop production. Changes in elevation, variability in soil nutrient levels, and subsoil chemical imbalances are just some of the factors addressed in this issue. Some of the strategies and precision agriculture technologies being used to manage variability that are discussed in the following articles include grid soil sampling, geographic information system (GIS)-based mapping, electromagnetic induction, optical sensing, and satellite imaging. Examples of how large-scale fertilizer recommendation systems are being refined to more relevant and appropriate guidelines that consider spatial variability at the farm-level in India and China are also included.

With the world population growing faster than ever and the increasing demand on food production, the judicious use of plant nutrients and other agricultural inputs is as important as ever. Paying attention to spatial and temporal variability when making nutrient management decisions can help both large-scale, commercial operations and small-scale, family farms contribute more effectively to improving global food security. BC

Dr. Roberts (troberts@ipni.net) is President of IPNI. Dr. Phillips (sphillips@ipni.net) is Regional Director, Southeast United States, and Chairman of the IPNI Spatial Variability Work Group.

Upcoming Events...

American Society of Agronomy-Crop Society of America-Soil Science Society of America (ASA-CSSA-SSSA) 2010 International Annual Meetings. Oct. 31- Nov. 4, Long Beach, California. www.acsmeetings.org

Information Agriculture Conference 2011. July 12-14, 2011. Springfield, Illinois. www.infoag.org

Precision Agriculture: Does It Make Sense?

By Viacheslav I. Adamchuk

In everyday language, the word "sense" normally refers to the five human senses, while "making sense" describes our efforts to interpret information that may seem confusing or conflicting. In precision agriculture, both meanings are important. While new equipment and software have been developed to practically implement site-specific crop management strategies, the question of which decision support mechanism to use remains. Thus, when viewing yield maps and/or aerial imagery, it is relatively easy to identify a problematic area within a given agricultural field, but it is not always obvious what should or, at least, could be done about the problem. This article discusses the different soil and crop sensing technologies that have been developed around the world to address this particular issue.

The concept of precision agriculture emerged from the belief that the variability of plant-growing conditions is one of the major contributors to field-scale differences in yield, and the idea that it could be beneficial to vary agricultural inputs according to local changes in soil properties (Robert, 1993).

To make precision agriculture work, a producer must be able to obtain high quality information about the spatial variability of different soil attributes that may limit yield in specific field areas. The inability to generate such information rapidly and at an acceptable cost using soil sampling and laboratory analysis remains one of the biggest obstacles to the adoption of precision agriculture. Both proximal and remote sensing technologies have been implemented to provide high-density data layers that reveal soil attributes. Remote sensing involves the deployment of sensor systems using aerial platforms or spacecraft. Proximal sensing requires placement of the sensor at a close range or even in contact with the soil being measured. This allows *in situ* determination of soil characteristics at or below the soil surface at specific locations (McBratney et al., 2005). Similarly, crop sensing at the level of the canopy or individual leaves provides data regarding the performance of individual plants, which can frequently be related to local growing environments.

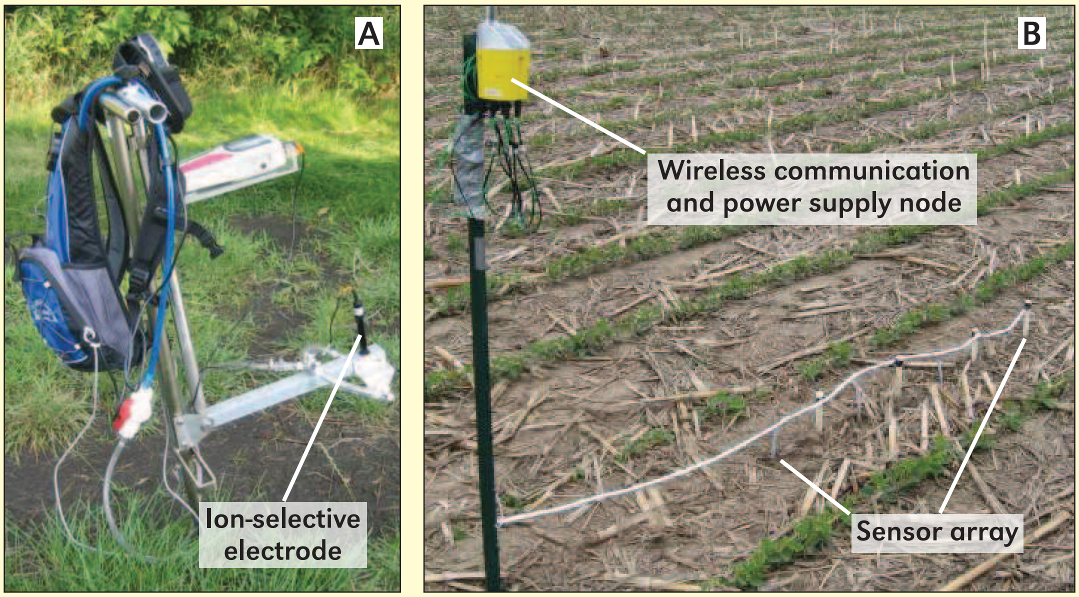

Figure 1. Instrumentation for point-based a) measurements of soil pH using a manual probe (University of Nebraska-Lincoln, Lincoln, Nebraska), and b) monitoring of soil matric potential and temperature (Crossbow Technology, Inc., San Jose, California).

Some proximal sensor systems can be operated in a stationary field position and can be used to: 1) make a single site measurement; 2) produce a set of measurements related to different depths at a given site; or 3) monitor changes in soil properties when installed at a site for a period of time. For example, **Figure 1a** illustrates a manual probe developed for on-the-spot measurement of soil pH or soluble ion activity (e.g., NO_3 or K) at a preset depth. **Figure 1b** shows a node location for the wireless monitoring of soil matric potential and temperature at four depths with a 15 minute time interval. Although single site measurements can be beneficial for a variety of applications, high-resolution thematic soil maps are typically created from measurements obtained while sensor systems are moved across landscapes. These on-the-go proximal soil sensing technologies have become an interdisciplinary field of research and development that seeks to provide essential tools for precision agriculture and other areas of natural resources management (Hummel et al., 1996; Sudduth et al., 1997; Adamchuk et al., 2004; Shibusawa, 2006). Proximal crop sensors have been used to determine physiological parameters (e.g., biomass, chlorophyll content, height, etc.) that indicate the spatially inconsistent status of agricultural crops, such as N deficiency or water stress (Solari et al., 2008; Samborski et al., 2009).

The sensors have been used to supplement either predictive or reactive approaches to differentiate management practice. The reactive (real-time) method of sensor deployment involves changing the application rate in response to local conditions assessed by a sensor at the time of application. By contrast, a predictive (map-based) strategy involves the use of many soil sensors to generate soil properties maps that can be processed and interpreted off-site prior to making decisions about the optimized distribution of agricultural inputs. Unfortunately, real-time sensing is not always feasible due to the time delay

Abbreviations: N = nitrogen; NO_3 = nitrate; K = potassium.
Note: Mention of a company or product name does not imply and endorsement or recommendation by the author or by the publisher.

or is not suitable if the spatial distribution of the sensed soil properties (e.g., soil electrical conductivity) does not change during the growing season. On the other hand, more dynamic parameters (e.g. crop performance indices) need to be defined in real-time so that differentiating an agricultural input can be accomplished in time to address the cause of variable crop performance. Therefore, different research groups have focused their recent studies on the most promising integrated method.

A great variety of design concepts exists, but most on-the-go soil sensors being developed involve one of the following measurement methods: 1) electrical and electromagnetic sensors that measure electrical resistivity/conductivity or capacitance affected by the composition of the soil tested; 2) optical and radiometric sensors that use electromagnetic waves to detect the level of energy absorbed/reflected or emitted by soil particles; 3) mechanical sensors that measure forces resulting from a tool engaged with the soil; 4) acoustic sensors that quantify the sound produced by a tool interacting with the soil; 5) pneumatic sensors that assess the ability to inject air into the soil; and 6) electrochemical sensors that use ion-selective membranes producing a voltage output in response to the activity of selected ions (e.g., hydrogen, K, NO_3, etc.).

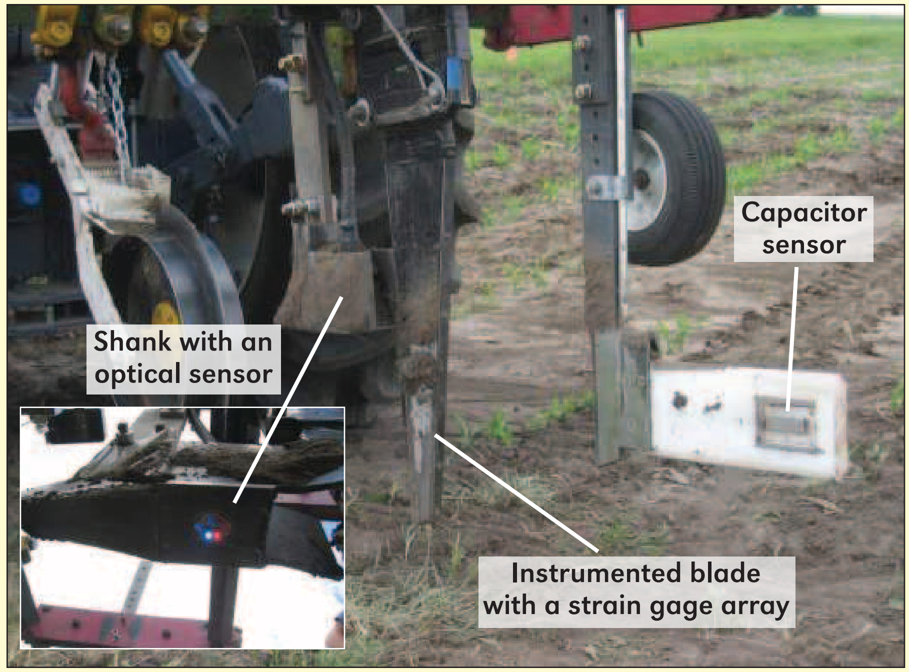

Figure 2. Prototype system comprised of mechanical, electrical and optical sensing components (University of Nebraska-Lincoln, Lincoln, Nebraska).

Ideally, a soil sensor would respond to the variability of a single soil attribute and would be highly correlated to a particular conventional analytical measurement. Unfortunately, in reality, every sensor developed responds to more than one soil property. Separating their effects is challenging; the process depends on many region-specific factors. **Table 1** provides a summary of the main types of on-the-go soil sensors with corresponding agronomic soil properties affecting the signal. In many instances, an acceptable correlation between the sensor output and a particular agronomic soil property was found for a specific soil type, or was achieved when the variation of interfering properties was negligible.

Table 1. Predictability of main soil properties using different soil sensing concepts.

Soil property	Soil sensors: Electrical and electromagnetic	Optical and radiometric	Mechanical	Acoustic and pneumatic	Electrochemical
Soil texture (clay, silt and sand)	Good	OK		Some	
Soil organic matter or total carbon	Some	Good			
Soil water (moisture)	Good	Good			
Soil salinity (sodium)	OK				Some
Soil compaction (bulk density)			Good	Some	
Depth variability (hard pan)	Some		OK	Some	
Soil pH		Some			Good
Residual nitrate (total nitrogen)	Some	Some			OK
Other nutrients (potassium)		Some			OK
CEC (other buffer indicators)	OK	OK			

As an example, **Figure 2** shows a prototype integrated soil physical properties mapping system (ISPPMS) developed at the University of Nebraska-Lincoln. **Figure 3** shows another example, a mobile sensor platform (MSP) integrating electrical conductivity and an automated soil pH mapping unit operated with a centimeter-level global navigation satellite system (GNSS) receiver. Both systems integrate different types of sensors. ISPPMS measured dielectric soil properties using a capacitor sensor in order to better interpret the meaning of soil mechanical resistance measurements produced using the instrumented blade and optical reflectance measurements made using a set of photodiodes. From a practical viewpoint, it appears such a system could be used to address spatial variability in soil water and organic matter contents as well as compaction. For producers using the MSP, the soil pH delineates field areas with acidic soils, and electrical conductivity measurements have been used to indirectly predict the amount of lime needed to raise the soil pH to a desired level (different amounts for different soil series). Using a centimeter-level GNSS receiver allows a producer to obtain a quality map of field elevation. In non-saline conditions, combining information about landscape topography with geophysical measurements such as electrical conductivity yields useful information about spatially variable soil water-holding capacity and potential for run-offs.

In general, proximal soil sensing data provide low-cost, high-density information on spatial variability. The resulting maps are integrated with digital field elevation maps to delineate field areas with significantly different crop production environments, as well as to prescribe locations for targeted soil sampling. Even when using proximal sensing, soil sampling

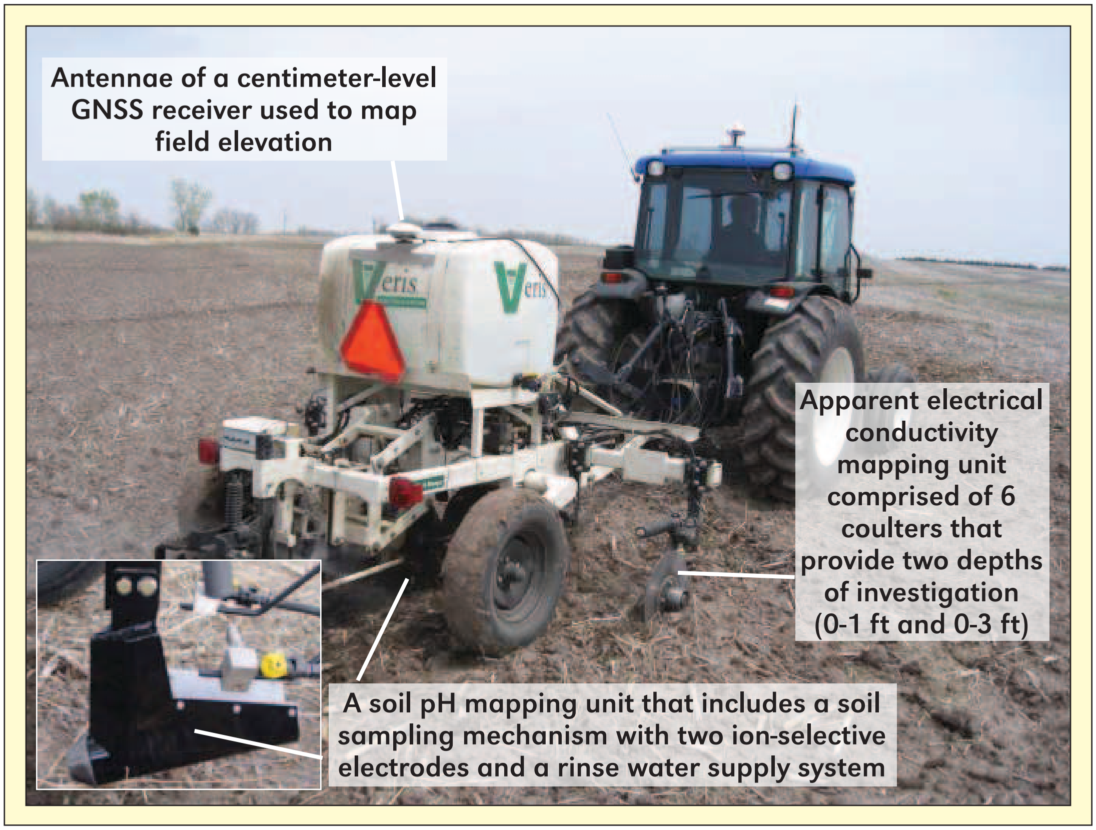

Figure 3. Veris® Mobile Sensor Platform integrating soil electrical conductivity and pH mapping units (Veris Technologies, Inc., Salina, Kansas) equipped with a Trimble AgGPS® 442 (Trimble Navigation Ltd., Sunnyvale, California) centimeter-level GNSS receiver.

and laboratory analysis remain critical components of the mapping process. However, the number of samples needed to characterize field variability can be much smaller than during systematic grid sampling as many soil properties follow spatial patterns that can be accurately delineated using on-the-go soil sensing. At this time, research is ongoing to determine which sampling strategy is the most efficient for enhancing the information value of on-the-go soil sensors (Lesch, 2005; Minasny and McBratney, 2006; de Gruijter, 2008; Adamchuk et al., 2008)

Crop sensors have been used to detect parameters related to the physical crop size using mechanical, ultrasonic, or other proximal sensing methods. Recently, optical reflectance sensors have become popular to detect the ability of the crop canopy to reflect light in visible and near-infrared parts of the electromagnetic spectrum. Physical crop size has been used to vary the use of agricultural chemicals according to the predicted demand, while crop status sensing has been used to alter the in-season supply of fertilizer and/or water to supplement local availability. However, it has been noted that variable soil conditions may require different rates of in-season fertilization to account for spatially different crop response.

Summary

Information on the variability of different soil attributes within a field is essential to the decision-making process for precision agriculture. On-the-go proximal soil sensing is the most promising strategy for obtaining much-needed high-density measurements of key soil properties. Proximal soil sensing systems are based on measurement concepts that are electrical and electromagnetic, optical and radiometric, mechanical, acoustic, pneumatic, and electrochemical. The major benefit of on-the-go sensing is its ability to quantify the heterogeneity (non-uniformity) of soil within a field and to adjust other data collection and field management strategies accordingly. The integration of different sensing systems in multisensor platforms may allow better prediction of agronomic soil attributes. Additional crop sensing options will allow producers to use these measurements to adjust in-season treatments in real-time. BC

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Spatial Variability and SSNM of Spring Wheat Production under Collective Contract Cropping

By Shao-wen Huang, Li-mei Huang, Shuang-quan Liu, Ji-yun Jin, and Ping He

Spatial variability of soil fertility (soil OM and available P, K, S, and Zn) and water in different parts of the study area were main factors influencing spatial variability of grain yield. Site-specific nutrient management (SSNM) treatments applied significantly more N and less P for relatively high soil fertility plots, and more N and K for low soil fertility plots than with collective contract cropping practice. SSNM for NPK increased yields by 8 to 19% and improved income by 455 to 520 RMB Yuan/ha.

Unbalanced fertilization along with a poor understanding of soil nutrient variability within fields can seriously affect crop yield and quality, economic returns, and environmental quality in China. During the last 10 years, data obtained from GPS/GIS technology and geo-statistics has played an important role in SSNM and the study of soil nutrient spatial variability (Jin, 1998). Recent examples of this type of research exist for traditional, smaller-scale family-operated crop production systems within China (Huang et al., 2003; Huang et al., 2006). However, spatial variability in China's collective contract crop production system and its corresponding management approaches have not been studied systematically.

China's collective contract crop production system generally uses the same amount of fertilizer for the same crop grown over several hectares to several hundred hectares, irrespective of the soil nutrient variability within these fields. This practice undoubtedly results in some areas of the field receiving too much fertilizer, whereas other areas receive too little. In this research, Keshan Farm of the northeastern China province of Heilongjiang was selected as an experimental area to analyze the spatial variability of soil nutrients as a basis for SSNM strategies for high quality and high yield spring wheat production as compared to the established collective contract system.

The spring wheat production field under study was a black soil (Phaeozem) site of 156 ha, with an east longitude of 125°50′5″ to 125°50′48″ and north latitude of 48°18′16″ to 48°19′15″. The region has a cold, temperate continental climate, with average annual rainfall of 500 mm, average annual temperature of 1.9° C (ranging between -30 and 30 °C) and a frost-free period of about 120 days annually. The region's main crops are spring wheat and soybean.

A total of 44 soil samples were collected on a 200 m x 200 m grid from 0 to 20 cm depth prior to the plots being sown for spring wheat in the study area **(Figure 1)**. Each sample was a composite of 10 sub-samples (7 cm core size) taken within a 5 m radius of the grid point. Soil pH, OM, and available P, K, Cu, Fe, Mn, Zn, Ca, Mg, S, and B were analyzed according to the Agro Services International (ASI) soil test procedure (PPIC Beijing Office, 1992). Soil NO_3-N was measured by spectrophotometer (Huang et al., 2004). Soil water was determined gravimetrically. Results showed that the major soil nutrient limiting factors identified were N, P, K, S, and Zn, with the percentage of soil samples below the critical value being 100, 32, 38, 75, and 94 in the experimental area, respectively **(Table 1)**. Significant differences in variations of different soil nutrients were observed, with larger values for NO_3^--N and available S (C.V. 49.9% to 73.7%), lower values for P, K, and Zn (C.V. 15.9% to 25.1%), and relatively smaller values for pH and OM (C.V. 2.7% to 11.7%).

Table 1. Soil OM (%), available nutrient contents (mg/L), and pH in study area.

Item	Minimum value	Maximum value	Mean	Standard deviation	C.V., %	Soil samples below critical value, %
pH	5.3	6.4	5.7	0.2	2.7	-
OM	3.9	7.5	6.0	0.7	11.7	-
NH_4^+-N + NO_3^--N	17	90	34	10.6	30.9	100
P	9	23	14	2.9	21.3	32
K	64	143	84	13.3	15.9	38
S	5	44	11	8.4	73.7	75
Zn	0.7	2.5	1.4	0.3	25.1	94
Ca	2,600	4,915	4,373	296.9	6.8	0
Mg	345	903	791	73.8	9.3	0
Fe	47	121	85	13.5	15.9	0
Cu	1	3	2	0.3	15.7	0
Mn	16	47	24	5.9	24.3	0
B	0.1	2	0.7	0.3	46.7	2

Critical values of soil nutrient fertility evaluation were 110 for NH_4 + NO_3, 12 for P, 80 for K, 2 for Zn, 5 for Mn, 10 for Fe, 12 for S, 401 for Ca, 122 for Mg, 1 for Cu, and 0.2 for B (44 sampling sites).

A patchy distribution of soil OM and available nutrient contents was generally observed, and contents of available soil P, K, S, and Zn in most areas were within one evaluation class **(Figure 1)**. Soil OM contents were negatively correlated with the altitude in this study area (r = -0.50), with relatively higher contents of soil OM being generally in lower altitude areas, and vice versa. Soil NO_3^--N contents were positively correlated with soil water contents (r = 0.62), indicating that soil water may be beneficial in accumulation of NO_3^--N in soils under rainfed condition.

Spring wheat was planted in all areas of the study area in 2007, but field history indicates that this is not always the case. The area has often been split between wheat and soybean

Abbreviations: N = nitrogen; P = phosphorus; K= potassium; S= sulfur; Ca = calcium; Mg = magnesium; Zn = zinc; Cu = copper; Fe = iron; Mn = manganese; B = boron; NO_3^--N = nitrate-N; GPS = global positioning system; GIS = geographic information system; OM = organic matter. Note: USD1 is equal to approximately 6.82 RMB Yuan.

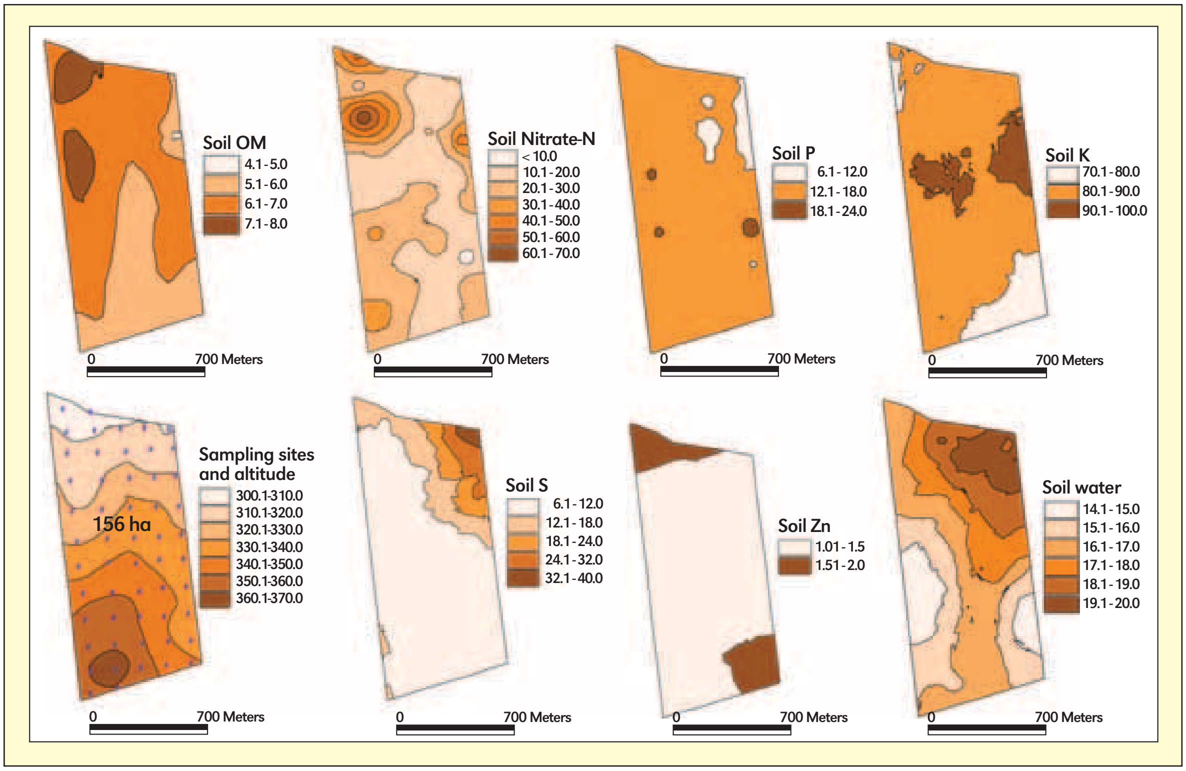

Figure 1. Spatial distribution of soil OM (%), available nutrients (mg/L), soil water (%), altitude (meters), and location of sampling sites in the study area.

Table 2. Response of site-specific balanced fertilization in spring wheat in the study area.

Fertility category	Treatment[1]	Yield, kg/ha	Yield increase, %	Income[3], RMB Yuan/ha	Income increase, RMB Yuan/ha
Relatively high soil fertility	NPKZnS	3,340	6.4	4,896	17
	NPKZn	3,344	6.5	5,175	296
	NPKS	3,288	4.7	4,870	-9
	NPK	3,396	8.1	5,334	455
	Collective[2] Contract Cropping	3,140	–	4,879	–
	No fertilizers	2,796		5,032	
Relatively low soil fertility	NPKZnS	3,076	21.3	4,083	291
	NPKZn	3,129	23.4	4,449	658
	NPKS	2,938	15.9	3,902	111
	NPK	3,014	18.9	4,311	520
	Collective Contract Cropping	2,536	–	3,791	–
	No fertilizers	1,817		3,270	

[1]N, P, K, Zn, and S denote N, P_2O_5, K_2O, Zn, and S, respectively. Application rate of N, P_2O_5, K_2O, Zn, and S is 67.5, 52.5, 37.5, 4.5, and 31.1 kg/ha, respectively, for relatively high soil fertility, and 90, 75, 60, 4.5, and 31.1 kg/ha for relatively low soil fertility.
[2]Application rate of N, P_2O_5, and K_2O is 47.3, 72.5, and 31.5 kg/ha for collective contract cropping.
[3]Price of N, P_2O_5, K_2O, Zn, S, and spring wheat (grain) is 4.35, 5.65, 5.00, 15.00, 8.70, and 1.80 RMB Yuan/kg, respectively.

during the same year, each crop with different fertilization practices.

Significant spatial variability of grain yield was found within the study area **(Figure 2)**. Grain yields ranged from 3,201 to 7,104 kg/ha (averaged 4,977 kg/ha; C.V. = 15.5%). Collective contract farming traditionally uses a blanket approach to its crop management, thus differences in soil fertility and water in different parts of the study area might be main factors influencing the spatial variability of grain yield. Significant spatial correlation relationships were found between grain yield and contents of soil nutrients and soil water. Correlation coefficients between grain yield and contents of soil OM, and available P, K, S, and Zn were 0.33, 0.51, 0.37, 0.53, and 0.32, respectively. The correlation coefficient between grain yield and soil water content was 0.37. Weight of 1,000 kernels is an important component factor influencing grain yield, as the correlation coefficient between them was 0.44. Spatial variability of 1,000 kernel weight was affected by soil available P content as the correlation coefficient between them was 0.32.

Spatial variability of grain yield was correlated closely and positively with total nutrient uptake (accumulation rates of nutrients in crop grain and straw) during the growth period in the study area **(Figure 3)**. Notable similarities in spatial distribution of total uptake of nutrients and corresponding contents of available soil nutrient were observed in the study area **(Figure 1 and Figure 3)**. Correlation coefficients between total N uptake and soil OM, between total P uptake and available soil P, and between total K uptake and available soil K were 0.44, 0.46, and 0.51 ($n = 44$, $r_{0.05} = 0.30$, $r_{0.01} = 0.39$), respectively **(Figure 4)**.

The SSNM techniques for high-yield spring wheat production in the study area were developed based on the regionalized soil nutrient GIS maps and a computerized fertilizer recommendation system based on soil test levels, yield goals, soil and climatic conditions, among other factors (Huang et al., 2007). SSNM treatments applied significantly more N and less P for relatively high soil fertility plots, and more N and K for relatively low soil fertility plots than collective contract cropping. Yield and profitability for collective contract cropping and SSNM are compared within

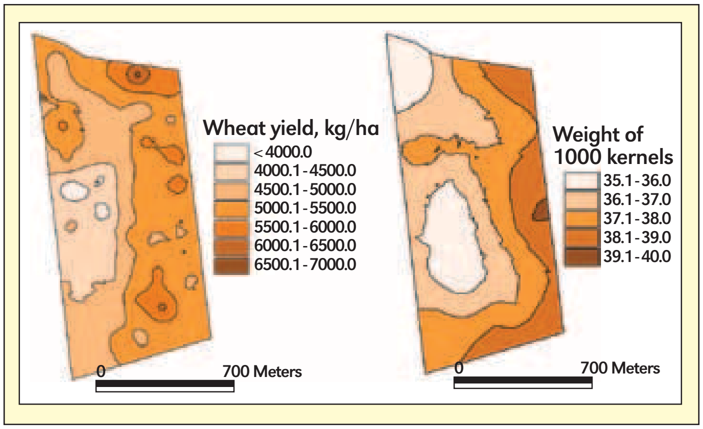

Figure 2. Spatial distribution of grain yield (kg/ha) of spring wheat and 1000 kernel weight (g) in the study area.

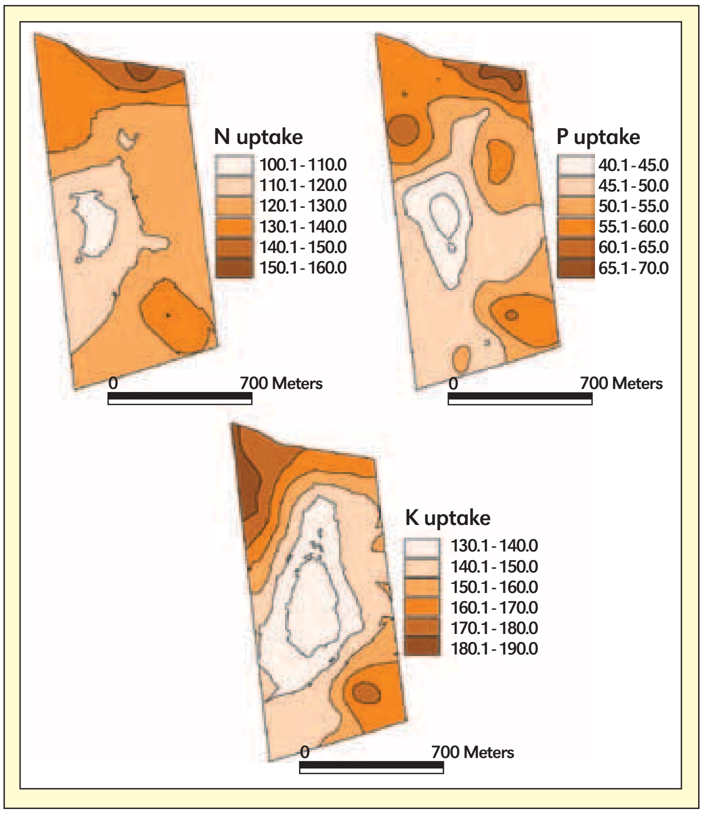

Figure 3. Spatial distribution of total nutrient uptake (kg/ha) during growth period of spring wheat in the study area.

relatively high and low soil fertility plots in **Table 2**. No yield response to Zn fertilizer or S fertilizer was found in these experiments. SSNM (NPK) increased spring wheat yield by 8.1% and 18.9%, respectively, within relatively high and low soil fertility plots, and also improved income by 455 and 520 RMB Yuan/ha, respectively. BC

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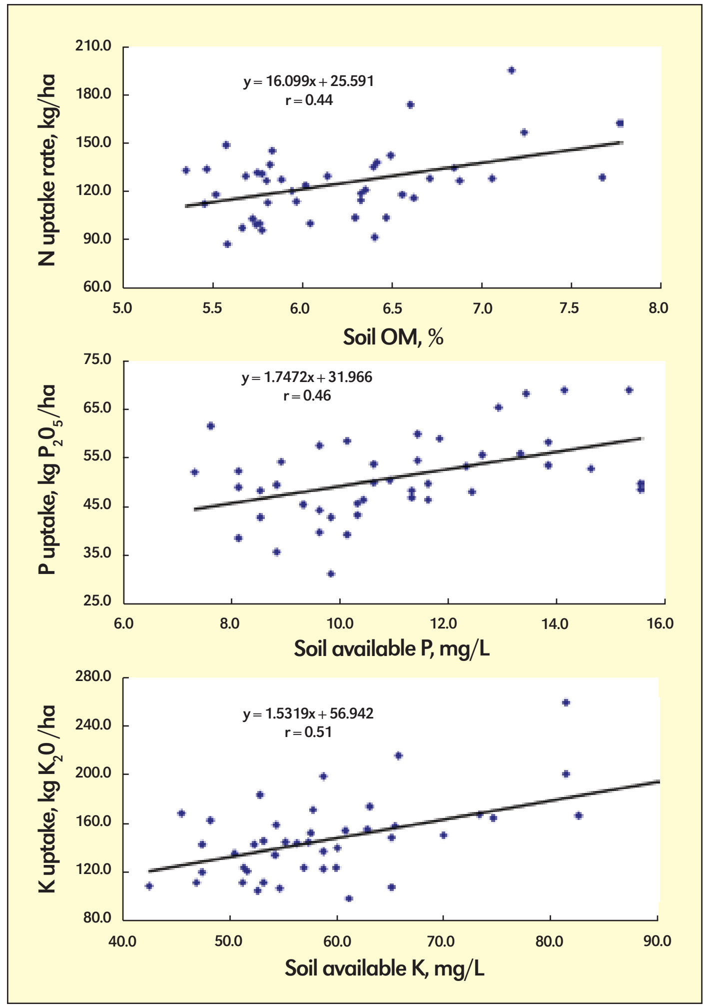

Figure 4. Relationship between total nutrient uptake during growth period of spring wheat and contents of soil available nutrients prior to spring wheat seeding in the study area. Significant at the 1% probability level.

Acknowledgments

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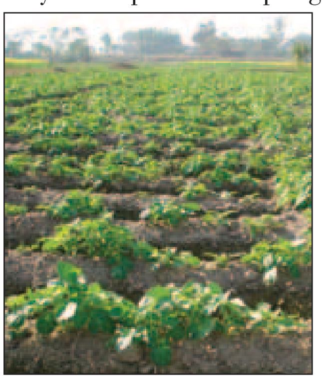
Use of Village-Level Soil Fertility Maps as a Fertilizer Decision Support Tool in the Red and Lateritic Soil Zone of India

By Wasim Iftikar, G.N. Chattopadhayay, K. Majumdar, and G.D. Sulewski

The combined influences of poor infrastructure, high implementation costs, and a diverse mosaic of small holders have limited the effectiveness of soil test-based fertilization programs in South and Southeast Asian countries. Geographic Information System (GIS)-based fertility maps represent an alternative decision support tool and this village-scale field study outlines a cost effective option of implementing improved nutrient management in large tracts of small-scale farming systems in Asia.

Soil test-based fertility management is an effective tool for increasing productivity of agricultural soils that have a high degree of spatial variability. However, major constraints impede wide scale adoption of soil testing in most developing countries. In India, these include the prevalence of small holding systems of farming as well as lack of infrastructural facilities for extensive soil testing (Sen et al., 2008). Under this context, GIS-based soil fertility mapping has appeared as a promising alternative. Use of such maps as a decision support tool for nutrient management will not only be helpful for adopting a rational approach compared to farmer practices or blanket use of state recommended fertilization, but will also reduce the necessity for elaborate plot-by-plot soil testing activities. However, information pertaining to such use of GIS-based fertility maps has been meager in India (Sen and Majumdar, 2006; Sen et al., 2008). The current study was initiated to assess the relative efficiency of GIS map-based soil fertility evaluation with regard to traditional soil testing in the red and lateritic soil zone of West Bengal.



GIS-based fertilizer recommendations focused farmers on nutrient management for their entire rice-potato-sesame crop rotation.

This on-farm study was conducted during 2007/08 at Meherpur Village of Birbhum District in the lateritic soil zone of West Bengal. The village represents 543 land holdings within a 76-ha area. The area falls under the hot, dry sub-humid zone, 60 m above mean sea level, with year round temperatures between 6.6 to 41.4 °C and a relative humidity range between 47.7 to 96%. Average annual rainfall is about 1,192 mm, mainly concentrated between June and September. Soils from this area are generally mixed Hyperthermic Typic Haplustalfs with sandy loam texture, moderate water holding capacity, acidic pH, and low fertility status. The crop system under study was a monsoon rice-potato-sesame cropping system.

Geo-referenced soil samples were collected on a 50-m grid and were analyzed for common soil productivity attributes including pH, organic C, available N, P, and K by standard methods (Jackson, 1973). The data were then integrated into a GIS platform (ESRI, 2001). An inverse distance-weighted method of interpolation created continuous surface maps for each parameter, allowing estimation of soil properties for unsampled points within the study area (Sen et al., 2008). See **Figure 1**. The spatial variability for each attribute was assessed using spatial descriptive statistics (Iqbal et al., 2005). A comparative assessment of soil pH and nutrient content values obtained from random sampling (10 samples from an area of about 20 ha) versus those predicted from the GIS found only minor variations in available N content. There was practically no variation in available P content under the two methods of evaluation **(Table 1)**. A larger difference was observed in the case of available K. Red and lateritic soils typically have low available N and P status, but soil K was well distributed between low, medium, and high fertility groups and was not well predicted through the GIS interpolation.

The relative effectiveness of recommendations generated through the grid-based, village-level GIS was evaluated against results obtained from common farmer practice, blanket fertilizer recommendations generated from the State, and field-specific, soil test-based recommendations within a monsoon rice-potato-sesame cropping system **(Table 2)**. Average yields for the initial rice crop were significantly higher under soil test and GIS-based soil fertilizer application over farmer practice

Table 1. Comparison of samples (%) that fall under low, medium, and high nutrient availability and pH categories under two systems of assessment.

	Low/Acidic		Medium/Neutral		High/Alkaline	
Parameter	Soil test	GIS	Soil test	GIS	Soil test	GIS
Available N	89	78	11	22	0	0
Available P	100	100	0	0	0	0
Available K	44	33	33	67	22	0
pH	56	67	44	33	0	0

Table 2. Nutrient rates (kg N-P_2O_5-K_2O/ha) used in each treatment and crop.

Treatments	Rice	Potato	Sesame
Farm	60-30-30	300-200-200	Residual
State	80-40-40	200-150-150	80-40-40
Soil test	Variable	Variable	Variable
GIS	Variable	Variable	Variable

Abbreviations: C = carbon; N = nitrogen; P = phosphorus; K = potassium; CD = critical difference, equivalent to Least Significant Difference; Rs. = Indian rupee (USD1 is equal to approximately Rs. 46).

Table 3. Yield of rice, potato, and sesame under different crop fertilization strategies.

Treatment	Rice: Yield, t/ha: Grain	Rice: Yield, t/ha: Straw	Rice: Economics[1], Rs.: Net return	Rice: Economics[1], Rs.: Return per Re. invested	Potato: Yield, t/ha: Tuber	Potato: Economics, Rs.: Net return	Potato: Economics, Rs.: Return per Re. invested	Sesame: Yield, t/ha: Seed	Sesame: Yield, t/ha: Stick	Sesame: Economics, Rs.: Net return	Sesame: Economics, Rs.: Return per Re. invested
Farm	4.2	4.6	20,592	1.90	28.7	38,210	1.50	0.8	3.0	3,928	1.22
State	4.4	5.0	21,544	1.91	22.5	20,962	1.30	1.2	3.9	8,278	1.51
Soil test	4.7	6.0	25,614	2.05	28.3	41,556	1.58	1.4	4.2	11,267	1.66
GIS (100-m grid)	4.7	6.0	24,760	2.02	27.6	39,128	1.55	1.4	4.1	11,457	1.68
CD at 5%	0.26	0.32	-	-	6.4	-	-	0.3	0.4	-	-

[1]Economic comparisons considered all fixed and variable costs including fertilizers (urea = Rs. 6/kg, SSP = Rs. 6/kg, KCl = Rs. 6/kg) and revenues from rice grain (Rs. 9/kg) and straw (Rs. 1.2/kg), potato tubers (Rs. 4/kg), and sesame seed (Rs. 20/kg) and sticks (Rs. 100/t).

and State recommended fertilization **(Table 3)**. Yield levels under soil test-based and GIS map-based fertilization were statistically at par, indicating feasibility for using GIS-based fertility maps for nutrient management. The following potato crop had equivalent tuber yields across treatments, which can be attributed to the tendency for farmers to use relatively high rates of fertilizer in potato. In sesame, yields were generally low due to a scarcity of irrigation water during the season. However, yields of sesame did follow a similar trend to that observed in rice. Thus, fertilizer recommendations generated from GIS maps were agronomically as effective as those generated from soil testing. Comparatively, the GIS and soil test-based fertilizer application was higher than state recommendation and farmer practice in rice and sesame. However, potato farmers applied higher amounts of nutrient than state recommendation as well as soil test or GIS-based fertilizer application. A complete economic assessment suggests net returns were maximized under field-specific recommendations in rice and potato, followed by GIS interpolation. In sesame, the GIS-based recommendations were marginally better than those obtained by field sampling. An additional consideration involves the cost of implementing new sampling strategies at the village-scale. Successful adoption of such technologies could rest on proposing a lowest cost solution which, in this setting, is advantageous to grid sampling through its lower sampling density **(Table 4)**.

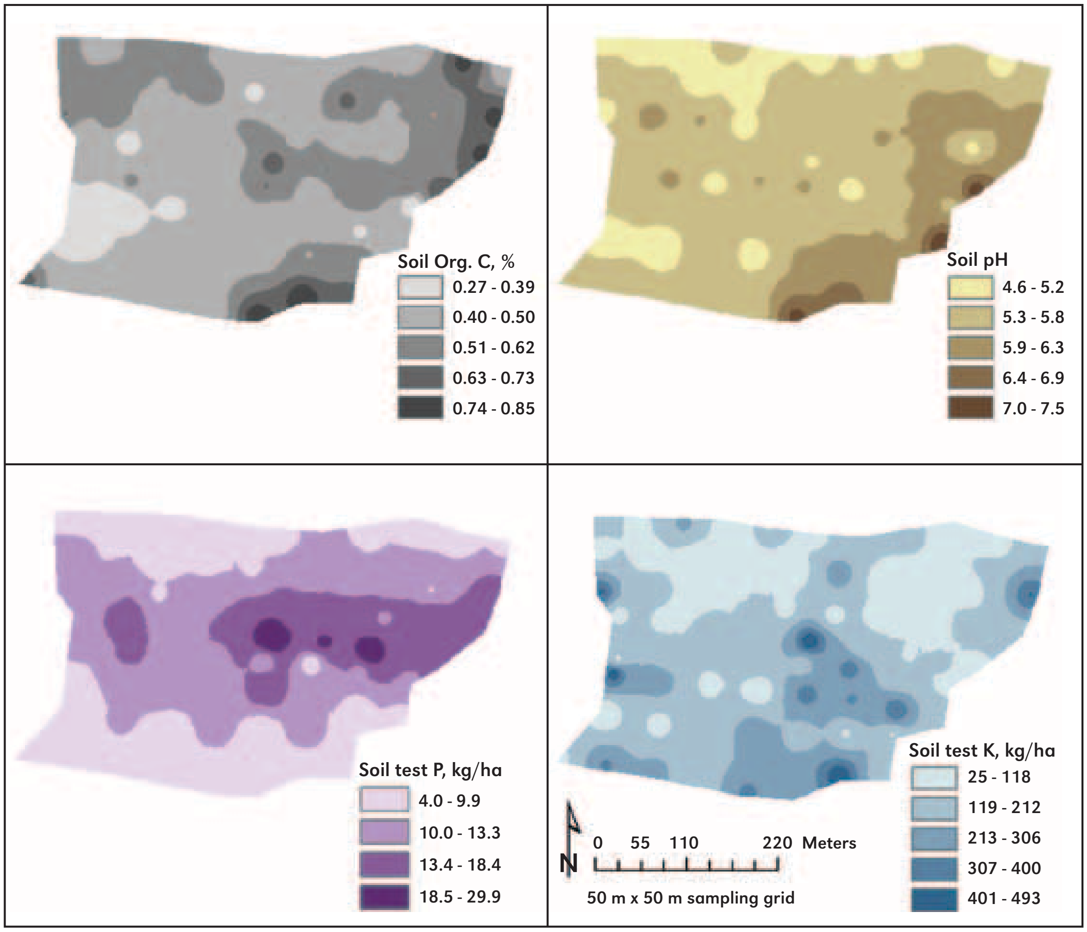


Figure 1. Maps show soil organic C, soil pH, soil test P, and soil test K for study at Meherpur Village.

It is likely that variation between estimates of nutrient availability under the two preferred systems was minimized when values were categorized and recommendations were generated. To substantiate this, a comparison was made between the mean fertilizer (NPK) doses under the soil test and GIS-based treatments for each crop. Results found the N and P application rates to be equal, but K rates varied slightly (data not shown), which again was attributed to comparatively higher variation in the availability of soil K.

Researchers also conducted another study simultaneously to assess the effect of grid size on map development and the predictability of soil fertility status. A substantial amount of research has tried to assess the appropriate sampling density needed to characterize the central tendency of soil properties with a specified degree of accuracy (McBratney and Webster, 1983; Webster and Oliver, 1990). A larger number of samples can produce more accurate maps (Mueller et al., 2001; Wollenhaupt et al., 1994); however, the cost of sample collection and analysis can be prohibitive. Previous research suggests

Table 4. Outline of implementation cost associated with improved village-scale sampling strategies.

Total number of land holdings		543
Total cultivated area of the village in hectares		76 ha
Actual cost of field-based soil testing (NPK analysis, commercial lab)		543 x Rs. 50 = Rs. 27,150
Actual cost of soil testing for GIS	50-m x 50-m sampling	304 x Rs. 50 = Rs. 15,200
	100-m x 100-m sampling	76 x Rs. 50 = Rs. 3,800
	250-m x 250-m sampling	19 x Rs. 50 = Rs. 950

Table 5. Yields (t/ha) of rice, potato, and sesame under different crop fertilization strategies and grid sizes.

	---- Rice ----		- Potato -	--- Sesame ---	
Treatment	Grain	Straw	Tuber	Seed	Stick
Farm	4.0	4.2	27.7	0.8	2.7
State	4.3	4.8	21.9	1.2	3.9
GIS (50-m grid)	4.5	5.8	27.2	1.4	4.1
GIS (100-m grid)	4.4	5.6	27.1	1.4	4.1
GIS (250-m grid)	4.3	5.3	25.5	1.4	3.9
Soil test	4.6	5.9	27.3	1.4	4.2
CD at 5%	0.3	0.5	1.6	0.2	0.3

that soil sampling on 60-m grids (Hammond, 1992) or even 30-m grids (Franzen and Peck, 1993) might be needed, but most commercial soil sampling is done on a 100-m grid basis.

To arrive at a cost effective grid size of sampling, researchers compared actual soil analysis values of pH, organic C and available P and K contents of random samples from the study area with values predicted from GIS maps using 50, 100, and 250-m grids. Predicted soil fertility levels were classified into low, medium, or high categories according to existing norms (Ali, 2005). Variation existed for soil parameters values under the three grid sizes, but the deviations from the actual soil test values were insignificant and made no difference when the values were classified into high, medium and low categories (data not shown).

Collecting soil samples within the fragmented landscape of the village of Meherpur, West Bengal.

Trials on the rice-potato-sesame cropping system were carried out using fertilizer recommendations predicted from these different grids, which were also evaluated against farmer practice, State recommendations, and field-specific, soil test-based recommendations. Higher rice grain and straw yields were obtained with either GIS or soil test-based fertilization compared to farmer practice **(Table 5)**. However, unlike the three GIS sampling grids, field-specific soil testing did generate superior rice grain yields over the State's blanket recommendation. No significant difference in rice yield was found among the three grid-based recommendations, although yields gradually declined with increasing grid size, to the point where yields obtained under the 250-m grid were significantly less than those obtained with soil test-based fertilization. For potato, farmer practice was once again a relatively high yielding treatment while the State recommendation provided the lowest yield overall. The 50-m and 100-m grid-based maps also provided comparatively better results than the 250-m map, such that these grid sizes generated tuber yields that were comparable to soil test-based fertilization. In sesame, farmer practice resulted in the lowest yield among all the treatments. Traditional practice in sesame largely relies on residual soil fertility after potato. The blanket State recommendation had higher seed and stick yields over farmer practice. However, considerably higher yields were obtained under the soil test-based and three grid-based recommendations. No significant differences in sesame seed yield were observed between soil test- and GIS-based fertilization as well as between the three grid sizes.

In contrast to developed countries, where precision nutrient management addresses in-field nutrient variability in large-scale individual operations, this study's approach addresses spatial variability of soil parameters between fields at the village scale. Geostatistical analysis and GIS-based mapping provided an opportunity to assess variability in the distribution of native nutrients and other yield limiting/building soil parameters across a large area. This has helped to increase awareness at the village scale, while helping farmers strategize for appropriate management of nutrients and strive for better productivity throughout their entire crop sequence. BC

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Optimizing Nitrogen for Wheat Growing on Hostile Subsoils

By John F. Angus, Charlie N. Walker, Judith F. Pedler, and Rob N. Norton

Nitrogen application to areas of wheat paddocks with high subsoil salinity, alkalinity, and/or boron (B) often gives low nutrient use efficiency and poor returns. These areas can be identified within a variable landscape using electromagnetic induction surveys. Paddock zones can be identified and then N managed according to the degree of constraint imposed by the hostile subsoils.

In the south-eastern Australian grain belt, there are large areas with subsoils that have high levels of salinity, sodicity, and alkalinity. These chemical imbalances result in subsoil compaction, toxic levels of B, and poor water availability due to salt. A survey of some of these paddocks showed that the subsoil limitations often – but not always – occur together **(Table 1)**. The constrained root growth that results prevents crops from using stored subsoil moisture and nutrients. In particular, crop response to N fertilizer on these soils is unreliable even in years of good rainfall, giving low nutrient use efficiency and poor returns to growers.

Table 1. Results of a survey of 36 paddocks in the southern Mallee and Wimmera, showing levels of B, sodicity (% of CEC), and salinity (electrical conductivity in 1:5 soil:water) in the top 60 cm of soil and some critical thresholds for those values.

Soil limitation and damage threshold	% of Paddocks
Boron (>8 mg/kg) in total	67
Sodicity (>15% ESP) in total	67
Salinity (>2 mS/cm) in total	67
Boron (>8 mg/kg) and sodicity (>15% ESP)	56
Boron (>8 mg/kg) and salinity (>2 mS/cm)	47
Sodicity (>15% ESP) and salinity (>2 mS/cm)	36

Table 2. Response of wheat yield to N delivery (40 kg N/ha) on soils with subsoil limitations (10 sites) and soils with no subsoil limitations (4 sites) between 1999 and 2004 in north-western Victoria.

	----------- Grain yield, t/ha -----------			
Sites	Nil	Presowing[1]	MRB[2]	Split[3]
All Sites	2.94 a	3.11 ab	3.52 c	3.30 b
Subsoil limited	2.80 a	2.92 a	3.45 b	3.17 ab
No subsoil limits	3.27 a	3.58 b	3.64 b	3.62 b

[1]Presowing N drilled approximately 2 weeks prior to sowing on 22 cm row spacing.
[2]Mid-row banding (MRB) between alternate sets of plant rows on 44 cm spacing.
[3]Split application, with half applied in MRB at sowing and half broadcast at stem elongation.
Yields with the same letter in the same row are not significantly ($p < 0.05$) different from each other.

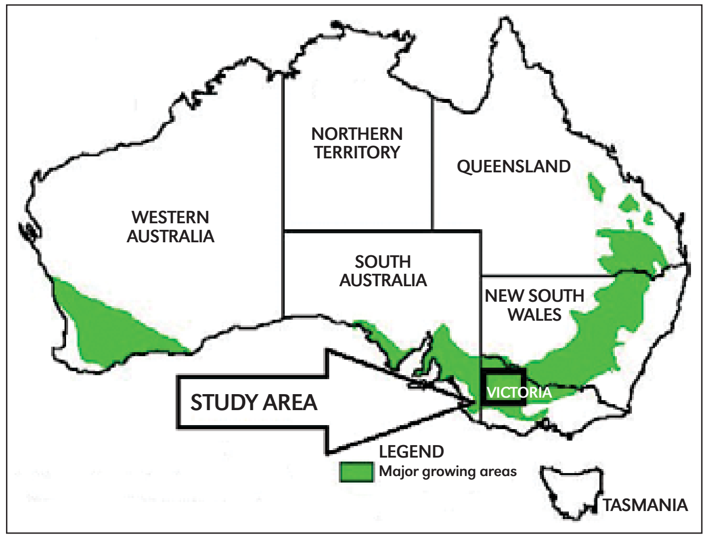

Figure 1. Location of replicated experiments and paddock scale N strips in north-western Victoria, Australia.

Map adapted from USDA World Agricultural Outlook Board and Foreign Agricultural Service.

View of paddock at Warracknabeal with N application subplots across the landscape.

Figure 1 shows the locations of a series of field experiments between 2000 and 2004 in north-western Victoria. The region has an average growing season rainfall of 392 mm, which varies from 104 to 596 mm. We evaluated a range of N management options for wheat at each experiment. Our hypothesis was that N responses could be improved if available N was kept in the topsoil where roots could access it, but that the concentration should be prevented from becoming so high that excess vegetative growth would exhaust the normally limited soil water. To do this, a range of split applications, deep banding, mid-row banding, predrilling, and topdressing before sowing were evaluated. Across the 14 sites over 5 years, the application of 40 kg N/ha at sowing had no significant yield response on sites with subsoil limitations, but splitting and banding did give significant responses to N **(Table 2)**. On the sites without limitations, delivery method did not make a significant difference in grain yield.

So, these data support the hypothesis that slowing the rate of N release, either by splitting the application or placing it

Abbreviations: N = nitrogen; ESP = exchangeable sodium percentage. Note: USD 1 is approximately equal to 1.14 Australian dollars (AUD).

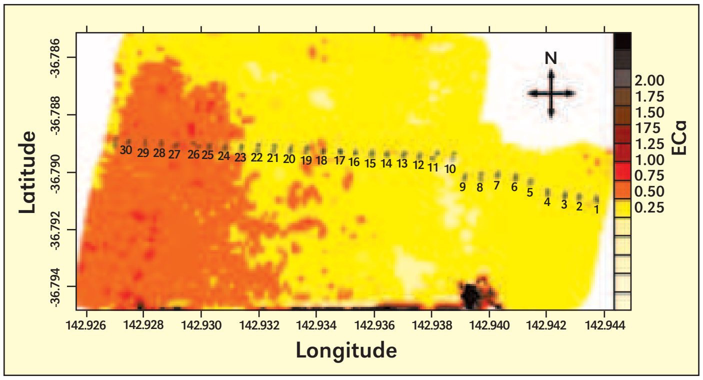

Figure 2. EM38 map, made in March, showing levels of apparent electro-conductivity, in mS/cm, measured in the horizontal dipole. Thirty paired sample sites are shown, within and beside the 10-m wide strip of urea, predrilled in May.

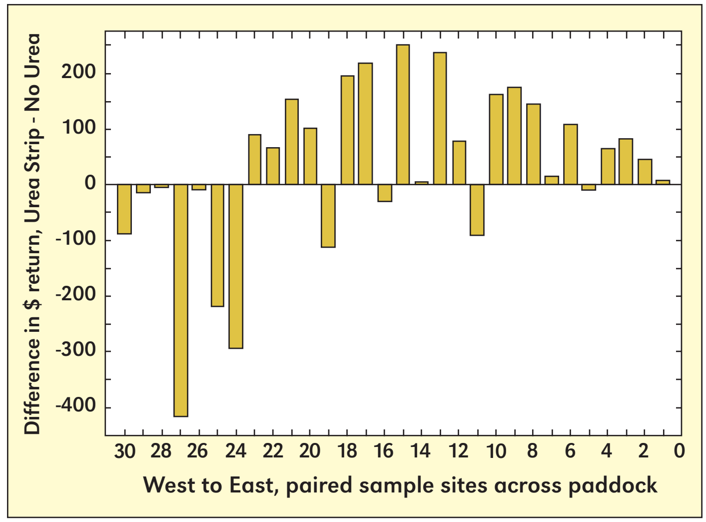

Figure 4. Differences in return (AUD) across a paddock, comparing application of 30 kg N/ha (Urea Strip) or none (No Urea). Return calculated using Australian Wheat Board (AWB) 'Golden Returns' matrix, with grain yield, protein, and screenings from 30 paired sample sites.

in bands, improved yields and nutrient use efficiency. This presents growers with an option to go to mid-row banding or to split N where soils have these limits. But here is the problem – subsoil limitations show high spatial variability and a uniform N application would supply too much N where the subsoils were a problem and possibly not enough N where the soils were not limited. So the key is to be able to easily and inexpensively find these areas within paddocks and manage those zones appropriately.

In 2001, a paddock north of Birchip was mapped for apparent electro-conductivity (ECa) using an EM38. The mapping was done in early March, to obtain the strongest ECa signals where the least subsoil moisture had been used by the previous crop. Poor use of subsoil moisture by a crop is a good indicator of hostile subsoil conditions. These hostile conditions frequently include salinity and sodicity, which give high ECa readings when the soil is moist. However, hostile subsoil conditions also include other possible problems such as B toxicity or soil compaction, which do not give high ECa readings. Using soil moisture remaining after harvest as the indicator of hostile subsoil therefore indicates a subsoil problem, but does not discriminate the possible causes. The EM38 map showed higher ECa in about a third of the paddock, where a highly variable gilgai flat stretched to the west **(Figure 2)**. Gilgai indicates undulating clay soils that shrink and swell with varying moisture. Sandier ridges had lower ECa, and presumably lower subsoil constraints to root growth **(Figure 3)**.

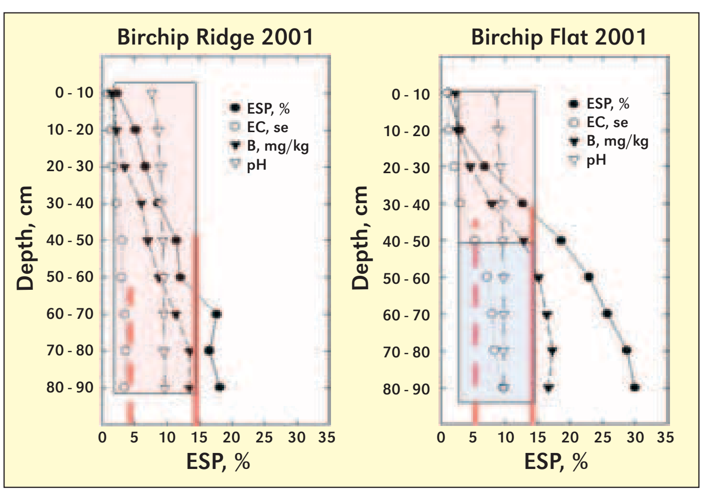

Figure 3. Soil chemical tests on two soil profiles... the ridge soils have an effective rooting depth of almost 1 m, while the soils on the flat have a rooting depth of about 0.5 m.

In May 2001, a 10-m wide strip of urea (30 kg N/ha) was predrilled the length of the paddock, prior to sowing H45 wheat in mid-June. In early August, 30 sites along the strip (at 50-m intervals) were sampled for soil characteristics. Soil cores were taken inside the urea strip, and in the adjacent crop where no urea had been pre-drilled. When the paddock was harvested in November, plots (10 m by 2 m) were harvested directly over those paired sample sites. Grain yield and protein content from the urea strip plots and the no-urea plots could thus be directly compared to soil characteristics at each site, and to ECa readings from the EM38 map **(Figure 2)**. Yield and protein responses to the pre-drilled urea changed with the paddock landscape, the soil characteristics, and ECa. Using yield, protein, and screenings for each plot, and the value of wheat produced, the return (AUD/ha) for each plot along the strip was calculated. The difference in return for applying urea (Urea Strip) or not (No Urea) show good agreement when the sample sites are lined up with the EM38 map **(Figure 4)**.

In the two-thirds of the paddock where the EM38 map from March showed an ECa of 0.25 mS/cm or less, it was either profitable or break-even to pre-drill urea. In the third of the paddock where the ECa was higher than 0.25 mS/cm, where the gilgai soils had high sodicity and high salinity, pre-drilling urea caused large yield and return reductions

Root growth and subsoil limitations at Warracknabeal site.

Hostile subsoils at Warracknabeal.

due to haying-off and small grain size.

In this paddock, the average wheat yield was 3.1 t/ha, with average protein of 10.5%. Using the map in **Figure 2**, if two zones were delineated by a line between sites 23 and 24 and the 'hostile' zone left without urea, the average yield for the whole paddock would have been 3.3 t/ha with a grain protein content of 11%. This resulted in an increase in return of nearly AUD 50/ha compared to the non-zoned paddock partly from reduced inputs and better grain quality on the areas with subsoil limitations. So it is thus possible to increase the average paddock yield and protein, with the same or even lower input costs.

Seven additional paddocks were mapped and strip-tested for N response over two more seasons. Using Australian classification (http://www.clw.csiro.au/aclep/asc_re_on_line/soilhome.htm), the paddocks were a mixture of vertosols (epicalcareous-endohypersodic, self-mulching, grey Vertosol), calcarasols (Epihypersodic, Pedal, Hypercalcic, Calcarasol), and sodosols (vertic and calcic, red Sodosol) typical of the region. Grain was harvested close to the site of each soil sample. The comparison of the yields in and out of the urea strip provided the estimate of N response.

The results varied from relatively high yields and large N responses during 2001, to small yields and small responses during the 2002 drought. The yield reductions to applied N in parts of the paddocks with high salinity were caused by haying-off, where there was insufficient soil water for grain filling. Of the eight paddocks, five showed large yield responses in areas of low salinity and decreasing responses as salinity levels rose and these data were combined to create an equation relating EM38 reading to the marginal yield response to applied N.

The N response equation was used to predict the zones in these paddocks where wheat would respond profitably to applied N. The definition of profit was when gross returns from additional grain exceeded double the cost of the applied N. A doubled cost was used to provide a 2:1 return on the N investment. The probability of profit at a particular site from a blanket N application was 21%. But when N was confined to the areas with salt concentrations less than 0.75 mS/cm, the probability of profit rose to 65% **(Table 2)**. Including grain-protein responses to N could justify N application to sites where yield responses alone were marginally unprofitable. Equally, avoiding N application to otherwise favorable areas could be justified where high-yielding crops have depleted the soil water reserves in the previous year and when little rain has occurred to recharge the profile.

The one-off cost of an EM survey is about AUD 5/ha. So, based on the information from the eight experimental paddocks, annual net returns from zoned application of, for example, 20 kg N/ha on 30% of the land would be about AUD 5/ha.

While this is not a high return and on its own might not justify the costs of investing time and money in precision agriculture, it is sufficiently encouraging to justify research to improve rules for variable application and to promote concentration of N fertilizer on responsive parts of paddocks with highly variable subsoil limitations. BC

Author Charlie Walker discussing the management of subsoil limitations.

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Temporal Variability of Crop Response to Fertilizer

By Robert Mullen, Greg LaBarge, and Keith Diedrick

Owing to the weather, crops respond differently to fertilizers from one year to the next. Weather controls processes of nutrient supply and loss from the soil, and crop nutrient demand. Improvement of nutrient use efficiency requires systems that take into account the influence of weather on these processes.

Visual response of corn to N at the Northwest Research Station near Custar, Ohio, in July 2008. Plot at left received 240 lb N/A, plot at right received no N.

Managing nutrient inputs for crop production can be a difficult activity when one considers all of the factors affecting nutrient supply from the soil and nutrient demand of the crop. Most agronomists can easily discern spatial patterns in these factors across a landscape, but addressing the issue of temporal fluctuations is a challenge. The goal of this article is to provide some insight into how temporal fluctuations occur from the perspective of nutrient supply and demand.

For soil-mobile nutrients like N, what dictates how much will be required? The factors that control crop response to N can be grouped into three categories: 1) from the supply side, how much N will the soil render plant-available (mineralization), 2) how much will be lost (leaching, denitrification), and 3) from the demand side, how much corn could be produced. While these are easily identified factors, they are quite difficult to quantify or predict precisely.

Mineralization rate is a function of the type of organic matter and the environmental conditions that persist throughout the growing season. Warm, moist conditions are likely to release more N than cool, dry soil conditions. The amount of N lost by denitrification and/or leaching is a function of precipitation patterns, soil drainage, air temperature, and availability of mineralizable carbon. Attainable yield within a growing season is a function of emergence, competition, and the presence or absence of stress. What is the one constant across the supply side of nutrients from soil, and subsequent demand of nutrients by plants? Variability in weather.

Ohio State University has been conducting a study evaluating corn grain yield response to sidedress urea-ammonium nitrate (UAN) in a corn/soybean rotation since 1998. The study evaluates corn response across five N rates: 40, 60, 120, 180, and 200 lb/A prior to 2006 and 0, 60, 120, 180, and 200 lb/A since. Each year, N response is modeled using a quadratic-plateau regression equation that allows us to determine the agronomic optimum N rate (AONR). The AONR is the lowest rate of N that provides maximum grain yield.

Abbreviations and notes: N = nitrogen; K = potassium.

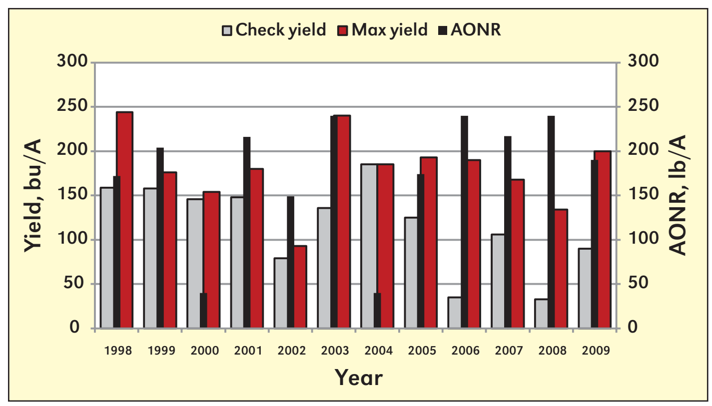

Figure 1. Maximum and check grain yields at the Northwest Research Station near Hoytville, Ohio, and the corresponding agronomic optimum N rates (AONR) necessary to achieve those yield levels for corn following soybean, 1998-2009.

As illustrated in **Figure 1**, the maximum attainable yield changes every year as does the amount of fertilizer N required for achieving that yield. Temporal fluctuations result in different optimum N rates at the same experimental location within the same rotation.

Traditional N recommendations have been based upon yield potential with the assumption that higher achievable yields require additional N to achieve those yields. We have learned that higher achievable yields do not necessarily translate into higher N needs (Sawyer et al., 2006).

Why do we frequently find no direct relationship between yield and optimum N rates in fields typical of the U.S. Corn

Belt? Mineralization of soil organic matter has the capacity to supply a large amount of N, precluding the need for supplemental fertilizer N. Additionally, if the loss potential of the growing environment is low, less fertilizer N would be required. Thus, from the supply side, the soil itself may supply enough to satisfy most of the plant's N needs, and the N supplied is less likely to be lost. Plant demand may also be low if corn productivity was adversely affected by the presence of some stress (most likely related to weather).

Taking 2004 and 2005 from **Figure 1** to illustrate the concept of temporal variability in fertilizer N requirement, notice that the attainable yield is similar between years (~190 bu/A), but the amount of fertilizer N required to achieve that yield level is completely different. What was different was the yield with a lower rate of N fertilization. The check treatment (treatment actually received 40 lb N/A with the starter) yielded 190 and 125 bu/A in 2004 and 2005, respectively. The decreased N requirement in 2004 was unlikely the result of lower loss potential, as the amount of rainfall that fell between May 1 and August 1 was 5 in. higher than in 2005. Thus, it would appear that much more N was mineralized in 2004 than in 2005.

Foliar application of a Mn solution by Keith Diedrick at the Northwest Research Station in Ohio.

While N fertilization lends itself quite well to a discussion on temporal variability, soil-immobile nutrients may also be influenced. Micronutrient nutrition provides another opportunity to discuss temporal trends in nutrient supply and demand.

Take manganese (Mn) nutrition of soybean as an example. Multiple fields in north-central Ohio can exhibit Mn deficiency symptoms, but it does not occur every year. In fact, sometimes it is not visible for much of the growing season and then suddenly it becomes visible in pockets across the field. Research at Ohio State University has demonstrated that response to foliar Mn can be agronomically and economically important, but it does depend upon the year **(Figure 2)**.

When soils dry, available Mn is oxidized to form manganese oxide, an insoluble compound. Thus, Mn is rendered unavailable to the plant. Application of foliar Mn under these conditions can result in positive agronomic and economic benefits (2007 season in **Figure 2**). Severe drought stress observed in 2008 likely precluded the need for Mn as a result of decreased yield potential (decreased demand). Lack of drought stress in 2009 resulted in adequate Mn availability from the soil and thus no response to a foliar application (increased supply).

Other nutrients can be subject to a similar phenomenon. Potassium stress is more prevalent in dry years in the eastern Corn Belt, especially on soils derived from 2:1 clays that can occlude K as soils dry. Conversely, in years with wetting/drying cycles, crop response to applied K may be smaller and less likely if soils release adequate K for crop nutritional demands.

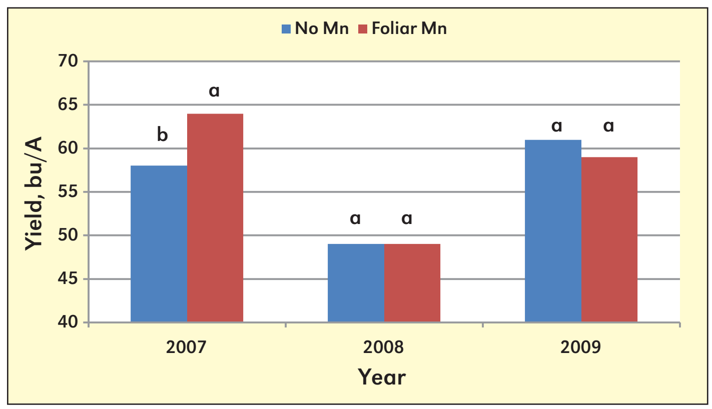

Figure 2. Response of soybeans to foliar-applied Mn at the Northwest Research Station near Hoytville, Ohio, 2007-2009. Bars with different letters above them differ significantly at the 0.05 probability level.

Temporal variability in nutrient need is strongly affected by weather and its impact on soil nutrient supply and plant nutrient demand. These temporal trends elucidate the need for tools to monitor plant nutrient demand and soil nutrient supply simultaneously. Plant tissue analysis, in-season soil sampling, and the use of newer technologies (remote sensing) will likely play increasingly larger roles in making nutrient decisions. BC

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Use of Active Optical Sensors for Crops in Brazil

By J.P. Molin

Active optical sensors have been evaluated as a new approach for precision agriculture and have been successfully used on grain crops and cotton for real-time, site-specific N management. The Precision Agriculture Research Group of the University of São Paulo has been involved with several activities related to the major optical sensors currently on the market (GreenSeeker, CropCircle, and N-Sensor).

During the last 3 years, the behavior of the normalized difference vegetation index (NDVI) in wheat, triticale, barley, corn, cotton, and sugarcane was evaluated using similar procedures in a series of field plots. Experiments have shown increasing NDVI readings in response to increasing N rates, foliar N content, and grain yield. In one of the investigations with wheat, a preliminary model for an in-season estimated yield index (INSEY) versus yield was obtained based on several locations and seven local varieties **(Figure 1)**, using the GreenSeeker sensor (Povh et al., 2008b).

In one of the field tests (Povh et al., 2008a), the objective was to establish an application rate for N using variable rate technology (VRT) in wheat based on the readings of the GreenSeeker sensor and the model from **Figure 1**. The experiment was conducted in a small field of 5.4 ha in the region of Campos Gerais of Paraná. The data were collected **(Figure 2a)** and post processed for the generation of NDVI **(Figure 3a)**, an N recommendation map **(Figure 3c)**, and in-season application with liquid N fertilizer **(Figures 2b and 2c)**. Nitrogen rates were simplified to 20, 40, and 60 kg/ha because of equipment limitations.

The experiment also consisted of strips receiving 120 kg N/ha, which served as a reference for the sensor, and strips that received 18.4 and 52.4 kg N/ha that were complemented with additional N based on the active optical sensor readings. Altitude was used as criteria for field stratification **(Figure 3b)**. At maturity, the field was harvested and yield mapped **(Figure 3c)**. In addition, a series of 96 plots (5 m by 9 rows)…eight for each treatment (variable and constant rate and each altitude class)…were manually harvested and the data were statistically analyzed by comparing yield averages with the Snedecor F test at 5% level of significance.

The results **(Table 1)** allow that spatial variability of NDVI exists, even in areas where constant rates of N were applied, showing that the crop responds in a non-uniform manner inside the same field. The methodology used for the variable-rate N application, using the crop as indicator, proved to be effective at determining N rates, with higher economy of fertilizer in areas with lower yield potential. Although reaching a high economy, the yield of the treatments receiving variable N rates were not statistically different from the treatments receiving fixed N rates.

In sugarcane in Brazil, there are a series of activities being conducted. The one in the most advanced stage is using the N-Sensor to indicate N application demands in commercial sugarcane fields. Eight fields of commercial sugarcane were evaluated under varying soil textural conditions ranging from sandy to heavy soils, ratoon stages, varieties, and harvesting time along the 8 months of the harvesting season. The sugarcane fields were scanned using the N-Sensor three times during the 2009 season, at 20, 40, and 60 cm of average stem height **(Figure 4)**. The measured reflectance maps were processed and divided into five classes. For each class, two samples were collected to measure aboveground biomass; total N content was analyzed and N uptake was calculated.

The project is generating a large amount of data and providing the proper measurements of parameters for modeling biomass and N uptake in sugarcane. According to the data already collected, the N-Sensor is able to detect the variability of biomass and N supply by the soil. The results indicate the presence of variability of biomass production and N-uptake in sugarcane resulting from distinct varieties, soil, and season period, but the differences are not affecting the detection of actual biomass and N-uptake by the N-Sensor. Based on the early results from this study, an initial algorithm is being proposed to conduct real-time, variable-rate N application based

Abbreviations and notes: N = nitrogen.

Table 1. Wheat yield data from plots in each altitude class.

	Wheat grain yield, Mg/ha					
	Elevation 1		Elevation 2		Elevation 3	
	Tier 1	Tier 2	Tier 1	Tier 2	Tier 1	Tier 2
Flat rate	3.3	3.5	3.0	3.0	2.6	2.9
Variable rate	3.3	3.6	3.2	2.9	2.7	3.0

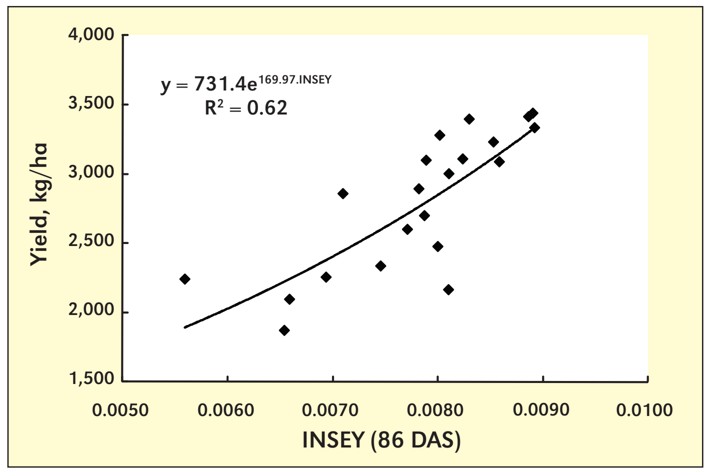

Figure 1. Exponential model relating INSEY calculated at 86 days after sowing (DAS) using a GreenSeeker sensor and wheat yield, based on experimental plots containing varying N rates and varieties.

Figure 2. Scanning the field with the sensor (A); N VRT application based on the post-processed map (B) and (C).

on sensor readings.

The use of field plots to evaluate the behavior of NDVI in sugarcane is labor intensive because of the amount of material needing to be manually harvested. Despite this difficulty, experiments were conducted to measure the effect on NDVI of increasing N rates, plant N content, and yield. In these studies, the sensor used was the CropCircle. Measurements were collected for varying soil textures ranging from sandy to heavy clay soils, different ratoon stages, and harvesting times. The fertilizer treatments were N rates ranging from 0 to 200 kg/ha. The initial results indicated that the sensor was able to distinguish among N rates, allowing for an algorithm capable of real-time application of N to be developed. **Figure 6** shows examples of readings collected at 50 and 75-cm height, on four experiments varying in crop age and soil types. The results indicate that the vegetation index behavior follows a similar pattern as the crop grows, but is still sensitive to field conditions, thus requiring specific models for different situations.

In another study on sugarcane, active optical sensors were tested to evaluate the correlation between

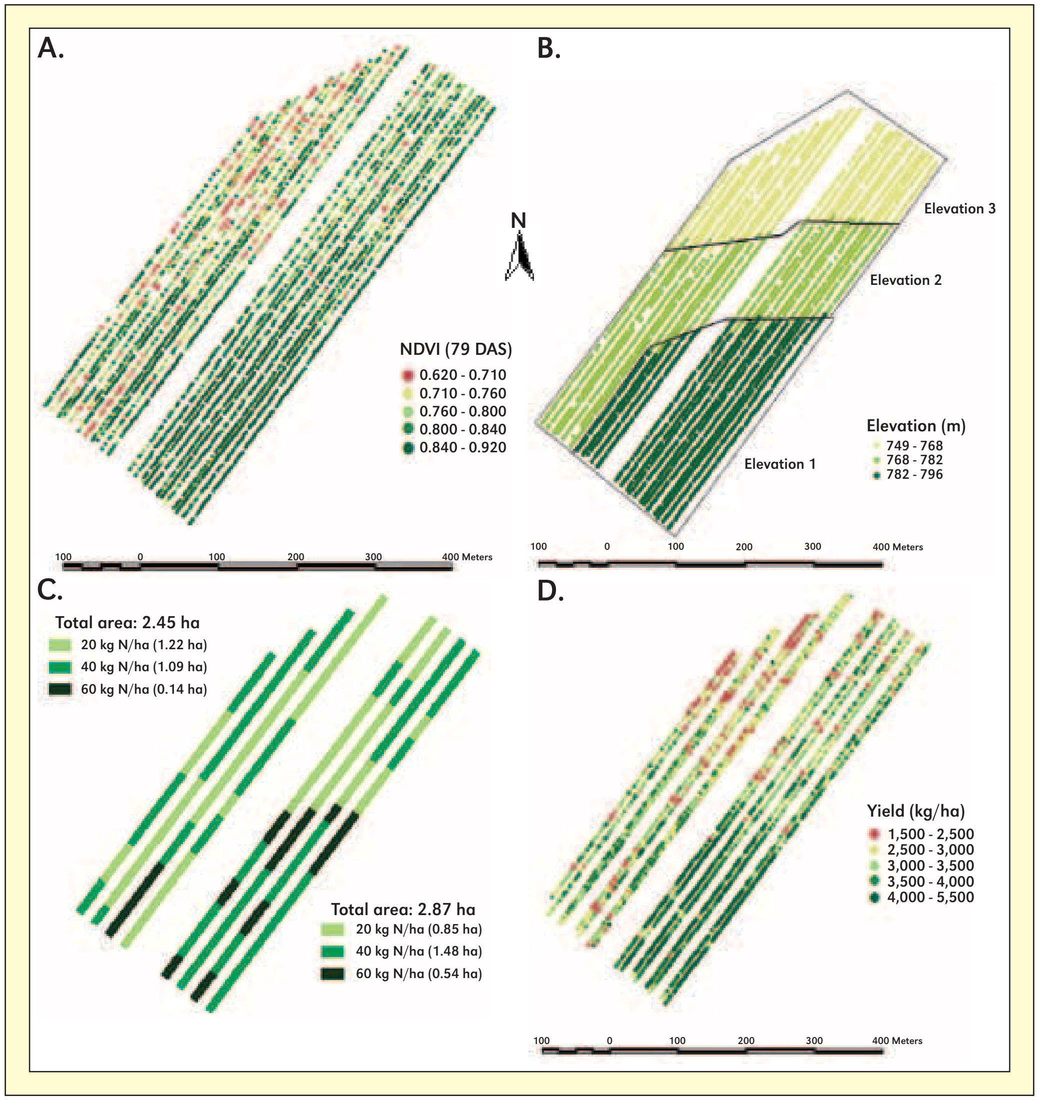

Figure 3. Map of NDVI at 79 DAS (A), three altitudes (B), N rated applied (C), wheat yield (D).

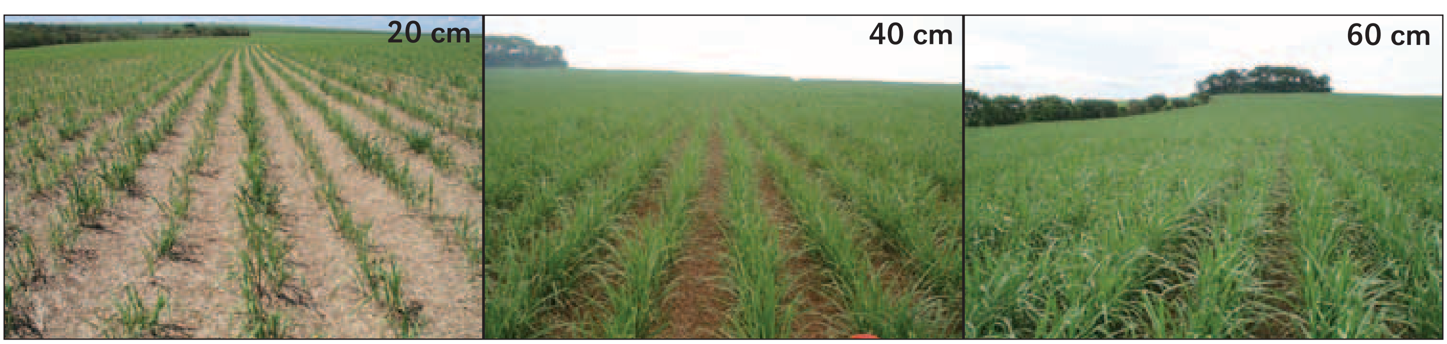

Figure 4. Sugarcane field status at the scanned stages.

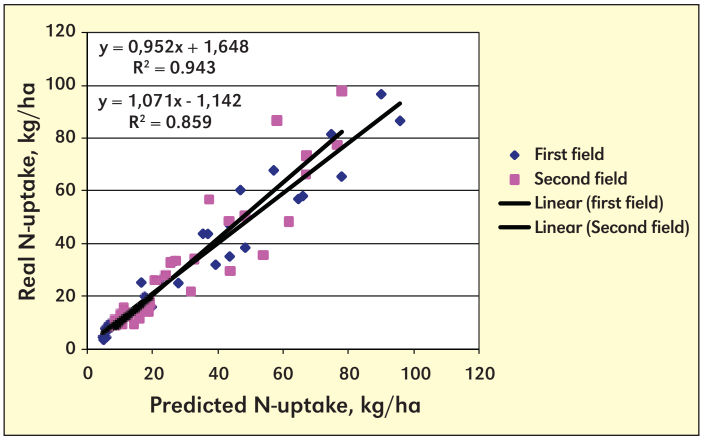

Figure 5. Sensor-predicted N uptake plotted against actual N-uptake for two fields, one on sandy soil and the second on clay soil.

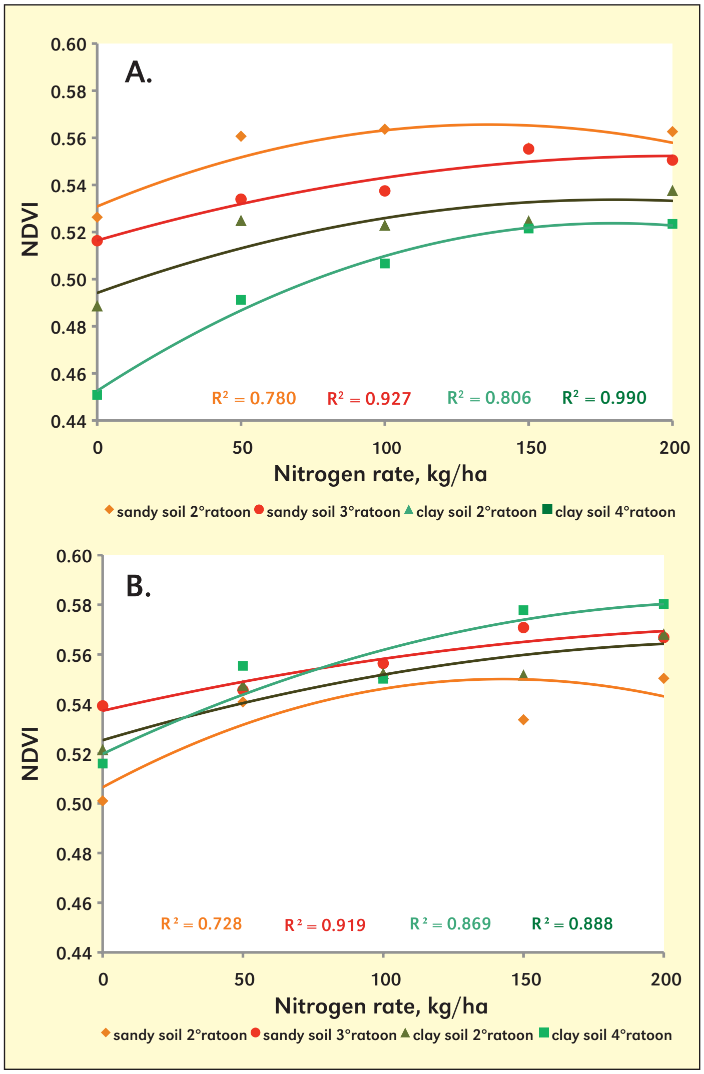

Figure 6. NDVI curves for N rates applied to four sugarcane experiments. Readings were collected at 50-cm (A) and 75-cm height (B) (after Amaral et al., 2010).

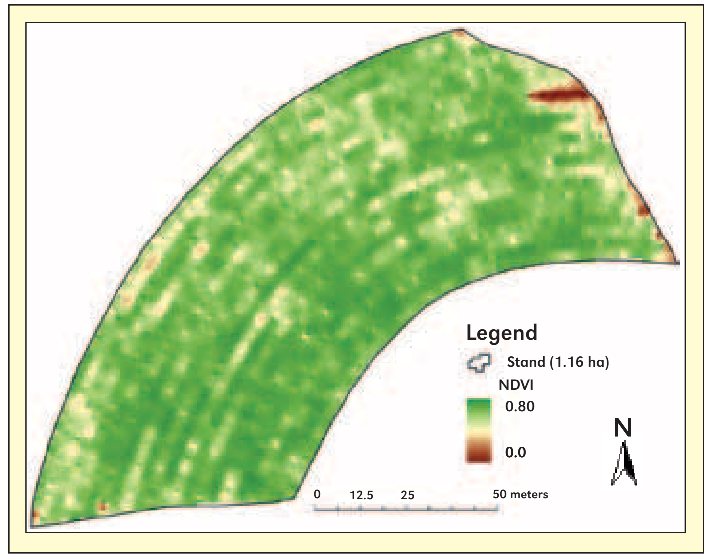

Figure 7. Map of NDVI levels obtained from sugarcane rows. Low index levels were associated with cane failures 100 days after planting (after Alvares et al., 2008).

NDVI and crop failures. Manual measurements are regularly conducted by a quality control crew between 2 and 3 months after planting and require significant labor. High levels of failures indicate the necessity of site-specific replanting or in some cases total replanting of a field. The same process may be used as criteria to decide on a ratoon field, when it has to be eliminated for replanting, based on crop failures. Initially, plots were located inside several fields and scanned. Results show high correlations between NDVI and the percentage of crop failure measured by the conventional method, indicating that it may be a promising alternative for failure measurement on sugarcane areas. As an example, one small field (1.16 ha) was scanned every two rows and the map **(Figure 7)** shows the vegetation index levels dropping in some spots, indicating the presence of failures that may be properly managed. BC

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Advances in the Use of Remote Sensors in Argentinean Agriculture

By Ricardo Melchiori

Research on the use of remote sensors to improve N use efficiency (NUE) in Argentina has shown important advances in integrating efforts among different organizations and companies. Variable rate management based on remote sensing would be an option to improve NUE under high yielding sustainable cropping systems.

Despite the great amount of data and information developed on N management for grain crops, worldwide NUE has been estimated at only 33% (Raun and Johnson, 1999). The need for NUE improvement promotes the continuous development of knowledge and field experiments, and the evaluation of new technologies, such as those associated with precision agriculture.

In Argentina, INTA (the national institute of agricultural technology), AAPRESID (the no-till farmers' association), and Profertil (a fertilizer company) developed a joint project that has been conducted since 2002 to promote the development and dissemination of sustainable N management technologies with emphasis on the improvement of NUE through remote sensing techniques.

Several researchers have shown that crop N deficiencies could be detected by remote sensors. However, stage of development, crop cover, accumulated biomass and nutritional status, and other factors affect the spectral response of the crops and the capacity for detecting N deficiencies. Strategies based on remote sensing require the availability of technologies to detect the deficiencies and the development of diagnostic methods and prescriptions to eliminate the N stress. It is also necessary to know how much and under which conditions the potential crop yield is affected, and how the environment might affect the response to N in late applications.

The author is shown taking measurements of NDVI in a corn (maize) crop at Paraná (Entre Rios).

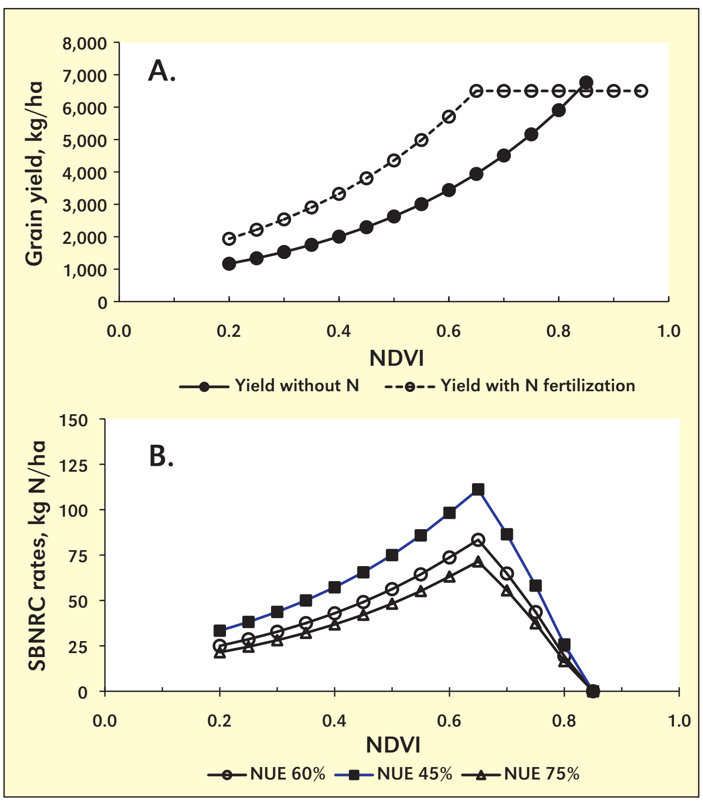

Figure 1. A) Theoretical recommendation model as function of the NDVI (Yield without/N: Yield without applied N; Yield with/N: Estimated yield with N fertilization.

B) N rate estimated for the relationships in (A) and three levels of NUE (NUE = 45, 60, and 75%).

Abbreviations and notes: N = nitrogen.

Current collaborative research in Argentina has proposed to: 1) develop and validate local procedures of diagnosis and recommendation of N fertilization based on remote sensing, and 2) evaluate N application timing to optimize the detection capacity of the N stress improving NUE. Results of this research have been published in Melchiori et al. (2004, 2005, 2006, 2007, and 2008a). This article summarizes the current knowledge gained during this project.

Development and Local Adjustments for the Use of Algorithms Based on Remote Sensing

The project in Argentina has followed the model developed by Oklahoma State University (OSU), described by Raun et al. (2005). Briefly, the method obtains predictive equations of crop yield as a function of the normalized difference vegetation index (NDVI). Algorithms predict N response at the projected yield level, and estimate the N rate required for a given NUE from the difference between yield estimations for the unfertilized and fertilized crop. **Figure 1A** and **Figure 1B** illustrate the theoretical recommendation model for wheat where the crop yield and the N response are estimated from NDVI determinations at specific crop growth stages (V10-12 in maize, or 1st-2nd node in wheat) in high-N reference plots

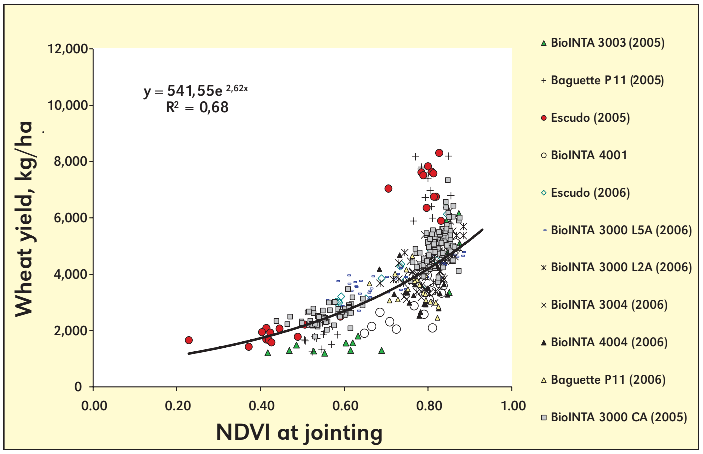

Figure 2. Wheat yield as a function of NDVI determined at beginning of the booting period with a GreenSeeker optical sensor. Data include results of several experiments with several varieties grown under differing water and N availability regimes.

The author (right) and Agustin Bianchini of AAPRESID check NDVI readings in maize, using a GreenSeeker sensor.

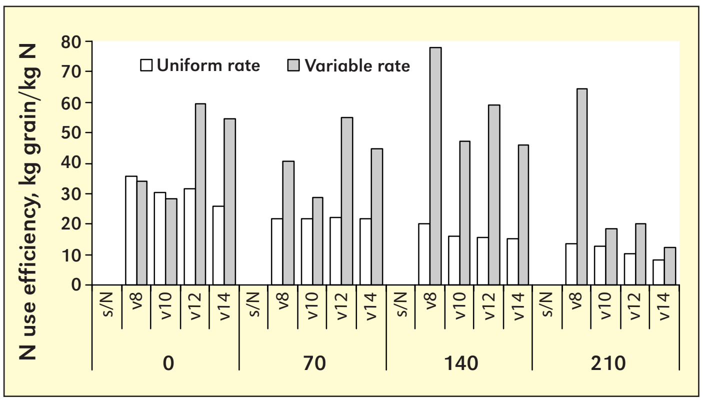

Figure 3. Nitrogen use efficiency (NUE) in maize following N fertilization between V8 and V14 using two strategies of recommendation: uniform rate vs. variable rate based on the use of remote sensors, at varying N rates applied at planting (0, 70, 140, and 210 kg N/ha) (averages 2002-2008).

and in the field of interest. The model restricts expected grain yield and NUE to pre-determined limits.

Local results in wheat crops growing under contrasting site conditions provided verification of these relationships and resulted in predictive yield models specific to Argentinean growing conditions. **Figure 2** shows, as example, the relationship between NDVI determinations with a GreenSeeker sensor and wheat grain yields at INTA Parana (Entre Rios province). This type of dataset was also developed for maize and subsequently generated equations were integrated into the library, available at: >http://www.soiltesting.oksate.edu/sbnrc/sbnrc.php<

Summary of Maize and Wheat Evaluations

The development of the model for maize required the evaluation of late-season N applications. Results from studies conducted in the USA have shown adequate N responses with N applications from growth stages V6 to V14 (Scharf et al., 2002; Randall et al., 2003). An extended N application period makes it possible to synchronize N availability with crop N demand, thus decreasing the risk in decision-making as many factors defining crop yield are already set. Although results have been encouraging (Melchiori et al. 2004, 2005, and 2006), it should be noted that row spacing of 52 cm (an expanding practice for maize in Argentina) will be necessary for the normal transit of machinery at later growth stages and that adoption of these late applications would also depend on the probability of precipitation immediately after.

Average results for seven growing seasons at Paraná (2002-2008), show that maize yield responses to late-season N applications are possible. Average N responses were similar with uniform N rates and variable-rate application using remote sensors, but the total N amount applied using the remote sensing-based model was lower, thus, improving NUE **(Figure 3)**.

In wheat, work included the development of the predictive equations relating crop yield and NDVI, as well as the evaluation of the effects of cultivars, growing cycles, tillering habits, planting N rates, and water availability. All of these factors affect NDVI determinations.

Nineteen strip field experiments were carried out from 2006 through 2008 at EEA INTA Paraná. Generally, the experiments included a strip with the N rate recommended for the field, a reference strip without N limitation, and a strip where N rate was determined using remote sensors (Melchiori et al., 2008b). In several cases, strips without N at planting and with only late N application were included. **Figure 4** shows the relationship between wheat grain yield and NDVI observed with field data and with the algorithm available at the OSU website: >http://www.soiltesting.okstate.edu<. It is quite similar to the theoretical model described in **Figure1a**.

Optimization of Variable Rate Systems

In recent years, we have started the evaluation of a variable-rate N application system (GreenSeeker RT 200, Ntech Industries, Ukiah, California, USA) in field studies. This system allows for the use of sensors on an applicator, whereby collected data are processed by a computer to prescribe N application rates and provide information for real-time variable N rate application.

Results evaluating different configurations for the number of sensor units indicate that acceptable estimations and

Wheat experimental field at EEA INTA Paraná (Entre Rios).

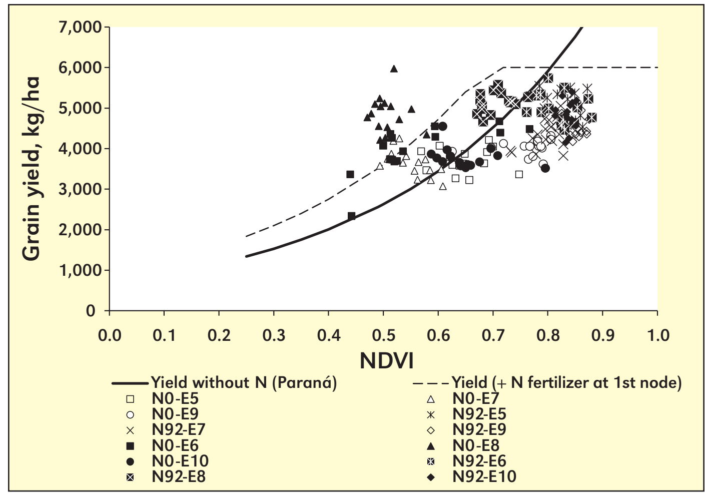

Figure 4. Wheat response to late N applications (1st node) under contrasting experimental conditions at Paraná (Entre Rios), 2006-2008.

variability of NDVI determinations for wheat and maize are obtained with 4 to 6 sensor units for standard fertilizer applicators. Also, NDVI variability decreases as crop development progress.

Future work should be oriented to expand the evaluation of remote sensors to a wider range of environmental conditions to make N application models more robust, and to promote the development of local techniques and equipment. BC

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Dr. William Raun (OSU), Agustín Bianchini (AAPRESID) and the participants of the Precision Agriculture Project of INTA at EEA Paraná.

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IPNI Joins as a Supporter and Exhibitor for AG CONNECT Expo in January 2011

As North America's new global agriculture exhibition, AG CONNECT Expo 2011 in Atlanta, Georgia, will feature international exhibit pavilions from major world regions, including Europe, South America, and Asia. AG CONNECT Expo 2011 runs January 8-10, with Preview Day January 7 by special admission. IPNI will have an exhibit at the event and will sponsor two educational presentations by Dr. Harold F. Reetz.

International exhibit pavilions at AG CONNECT Expo bring an added dimension to the show floor, providing attendees with a convenient and cost-effective opportunity to examine new products and technologies from companies around the world. Key countries already signed on to sponsor pavilions

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at AG CONNECT Expo 2011 are Argentina, Brazil, Canada, China, Germany, and Italy. There will also be a European pavilion at the show. The inaugural AG CONNECT Expo, in 2010, had approximately 20% international registrants with more than 60 countries represented.

AG CONNECT Expo is organized by the Association of Equipment Manufacturers (AEM), with direction from industry companies and organizations. For more information on AG CONNECT Expo 2011, visit www.agconnect.com.

Precision Management Zones Increase Sugar Production in North Dakota and Minnesota

By David Franzen, Greg Richards, and Tom Jensen

Use of variable rate N field management zones – based on sugarbeet leaf color differences derived from satellite imagery – has successfully increased crop yields and the amount of refineable sugar produced per acre of land where sugarbeets are grown in rotation in eastern North Dakota and western Minnesota. The development of a system to subdivide fields into three differentially managed zones is based on research and field experience looking at N management for sugarbeet production. The three management zones are simply characterized as low, medium, and high available N zones, and N and other nutrient rates are adjusted for each zone, based on soil test results.

Management of N, although important for most agronomic crops, is especially critical when growing sugarbeet to achieve desired yields and refineable sugar quality of the beet roots. Sufficient N is needed early in the growth of the beets to grow adequate leaf canopy to make maximum use of photosynthesis and then to store the photosynthetically produced sugars in a sufficiently developed root structure. If excess N is available later in the growing season, the root yield of sugarbeet can be high. But undesirable concentrations of nitrate (NO_3^-) and ammonium (NH_4^+) N compounds, as well as protein, are present in the roots. This reduces the amount of quality sucrose-sugar produced per acre when the beets are refined.

Research examining the relationship between available N and sugarbeet root yield and quality has been on-going for almost 130 years. The earliest recorded studies were in Bernburg, Germany, in 1882 at an experimental research station investigating the mineral nutrition of sugarbeet (Winner, 1993). Numerous studies have subsequently increased the knowledge of how to manage N to achieve desired yields and quality of sugarbeet. One example is the research reported by Bauer and Stevenson (1972) that shows sucrose yield reaching a maximum at a moderate rate of N (100 lb N/A), but decreasing if a higher N rate is applied…even though root yield continued to increase **(Table 1)**. To accurately manage the N supply for a sugarbeet crop, the first step is to determine the amount of available residual N in the soil following the previously harvested crop, and supplement this residual N with added N as fertilizer required for the target yield of sugarbeet. Residual N can be estimated by taking soil samples in the fall after harvest of the previous crop, and having them analyzed for mineral N content, usually NO_3-N. Initial depth of sampling was 24 in., but subsequent research has shown sampling to a depth of 40 to 60 in. is useful because of the deep rooting nature of sugarbeet (Franzen et al., 1999a).

This method of soil sampling can be used to help determine the appropriate rate of fertilizer to add for each crop in the crop rotation used. However, it was observed that field variability usually resulted in sugarbeet growth such that some areas of a field appeared deficient in N, some moderate in N, and some excessive in N. Soil testing these three areas separately determined that residual N levels increased from levels of relatively low to medium, and high. Smith (1996, 1997) conducted site-specific N application studies for sugarbeet in rotation, and found that when whole field soil NO_3^- average levels were used to develop fertilizer rate applications, the same soil N variability level patterns persisted through the crop rotation. He suggested that sugarbeet leaf N content should be used to prevent excessive N application within the rotation. Considerable N is present in the sugarbeet leaves or tops and the greener the color of the leaves the greater the N present. Most of the N present in the leaves is returned to the soil after harvest of the sugarbeets, and it becomes available to a subsequent crop (Franzen, 2004).

Abbreviations: N = nitrogen; ppm = parts per million; USD = U.S. dollar

Table 1. Effect of N application over three sugarbeet varieties on sugarbeet yield, sucrose concentration, impurity index, and sucrose yield, Oakes, North Dakota.

N rate, lb N/A	Root yield, ton/A	Sucrose concentration, %	Sucrose yield, ton/A	Impurity index, ppm
0	21.8	17.0	3.7	429
51	22.3	16.7	3.7	482
100	24.0	16.4	4.0	534
200	24.6	15.3	3.7	750

Initial soil nitrate-N to 24 in. was 50 lb N/A

Satellite imagery was used to distinguish between "high-N" and "low-N" tops in commercial fields (Moraghan and Smith, 1996). Three reflectance bands... representing low N status, medium N status, and high N status sugarbeets... were used to form the image. Moraghan et al. (1997) separated sugarbeet canopy color from images obtained from late August through early October into yellow, yellow-green, and green. Moraghan subsequently indicated (Sims et al., 2002) that providing N credits to "green" sugarbeet tops was practical.

Franzen et al. (1999b) used Normalized Difference Vegetative Index (NDVI) imagery from the Landsat 5 satellite to delineate zones for applying sugarbeet top credits against N recommendations for wheat following sugarbeet in rotation. NDVI is the ratio of the reflectance of infrared minus red light, divided by infrared plus red light. NDVI is related to relative biomass, crop type, plant health, and nutrition. Yields of areas where credits were given were similar to yields in areas where credits were not needed. Careful attention to N application rates to crops within the rotation, directed by soil sampling, application of N, and sugarbeet top N credits within these image-based zones, resulted in improved sugarbeet quality. In 2002, approximately 20% of the 2002 sugarbeet acreage in the Red River Valley (of crops immediately following sugarbeet) were given a N credit based on this research, with a reduction in fertilizer costs of about USD50/A. Other benefits

Table 2. Effect of zone fertility management on yield, 2003-2007 (ACSC Database).

Management method	Refineable sugar, lb sugar/A	Refineable sugar, lb sugar/ton fresh beets	Revenue, USD/A
Zone	7,567	388	1,022
Conventional field	7,315	338	986
Advantage for zone over conventional management	252	50	36

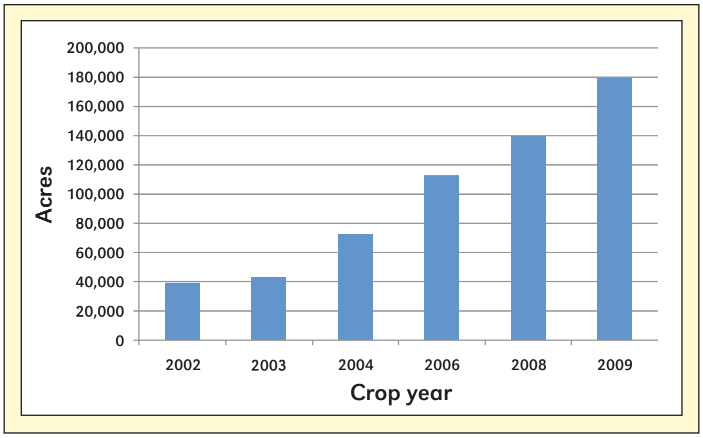
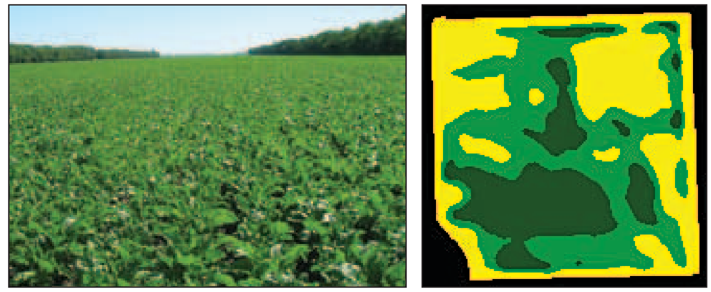


Figure 1. Use of zone management from 2002 to 2009 in eastern North Dakota and western Minnesota (American Crystal Sugar Company 2007, and personal communication 2010).

included reduced lodging of small grains and lower residual N levels in fields returning to sugarbeet in 2 to 3 years.

The use of the sugarbeet leaf color management zones based on satellite imagery has continued to increase since the initial development and use in 2002 **(Figure 1)**. It is estimated that in the crop year 2009, approximately 43% of the 425,000 acres of sugarbeet grown under contract for the American Crystal Sugar Company (ACSC) in eastern North Dakota and western Minnesota used zone management as described above. Sugarbeet growers have the fertilizer variable-rate applied on their fields, usually by their custom fertilizer retailer using prescription variable rate files developed using zone management technology. As growers and ACSC agronomists have worked with using this method of N management, they have found that the management zones could be further refined by using not only the sugarbeet leaf imagery, but also digital topographic maps, and yield maps of all crops in rotation. Many fields are separated into variable rate fertilizer application zones using a combination of the three data information sources mentioned above (ACSC, 2008). It is important to mention that all fields grown under contract with ACSC are managed at the very least using conventional soil sampling on a field average basis to develop fertilizer rate recommendations. The advantage to using the zone management system is that it results in more refinable sugar per acre and per ton of beets, and results in increased revenue per acre for growers **(Table 2)** (ACSC, 2008).

Use of precision variable rate technology applied to management zones based on sugarbeet leaf color has been used effectively in eastern North Dakota and western Minnesota.



A sugarbeet production field as seen by eye (left) compared to the satellite-derived leaf color image on the right. (Source: ACSC).

It is expected that variable rate fertilizer technology will continue to increase in use by growers having sugarbeet contracts with ACSC. There is consideration to further refine the three management zones now used (up to five management zones) to more effectively supply the appropriate N rate to zones requiring intermediate N rates in between the existing zone categories. This will help to maximize sugar production and further increase grower revenues.

Another use being considered for zone management technology is to increase or decrease planting rates of the sugarbeets. For example, the high residual N zones are often consistently higher-yielding compared to the other zones in all crop phases of crop rotations. By increasing plant populations or stands of sugarbeets in these zones, there may be incremental increases in sugarbeet yield and refined sugar per acre of crop. Conversely, in consistently lower yielding management zones, lower than average plant stands may save money on seed costs and not decrease attainable yields. This variable rate planting technology is part of on-going research (ACSC, 2010). BC

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Spatial Variability of Soil Fertility Parameters and Efficiency of Variable Rate Fertilizer Application in the Trans-Volga Samara Region

By A. Tsirulev

Precision agriculture approaches were compared to routine current management for conducting soil fertility assessment in a recent study. Measurement of soil spatial variability in precision agriculture was accomplished using GPS equipment with precise fixing of soil sampling points, automatic soil sampler, and special software to map various soil fertility parameters, including soil nutrient content. Both spring wheat yield and net profit were highest with variable rate fertilizer application in the on-farm research experiment.

In this region of Russia, routine soil sampling for agrochemical analysis is done manually and, most importantly, without precise reference of sampling points to a map. Thus, during the next soil sampling it is not possible to claim with confidence that soil samples are taken from the same place. Such an approach makes it difficult to characterize the status and dynamics of soil fertility changes in the field that are needed for fine tuning of fertilizer application rates. This negatively affects both the economics of agricultural production and the environment (Yakushev, 2002).

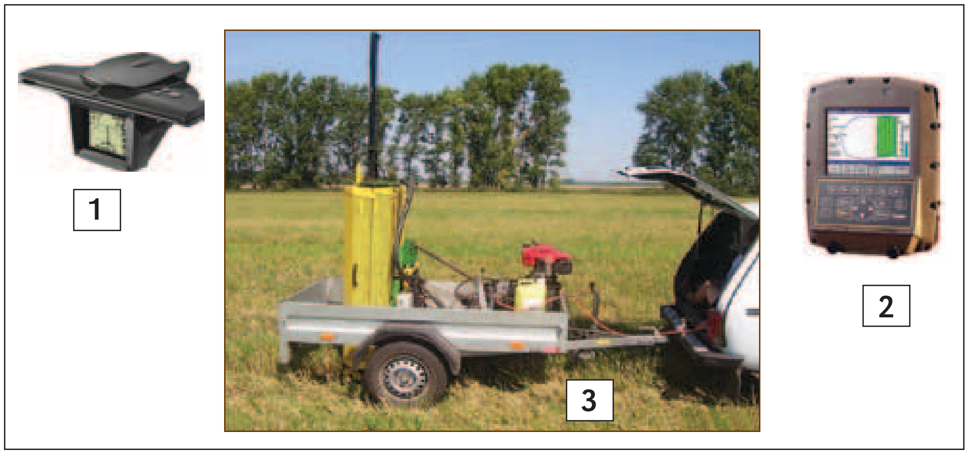

Figure 1. Automatic soil sampling equipment: 1 – GPS navigation system; 2 – field computer; 3 – soil sampler.

The Ministry of Agriculture and Food of Samara Oblast initiated and supported a special research project to test a new method of discrete soil sampling for soil fertility survey using GIS and GPS navigation systems. The research work was conducted on fields of the agricultural enterprise Samara-Solana in Stavropol District of Samara Oblast. Common chernozem is a predominant soil type of the area. The variability of four soil fertility factors, including organic matter (humus) content, available P and K... extraction with 1% $(NH_4)_2CO_3$... and soil pH, was measured in 2007 in 10 fields totalling 776 ha.

Soil sampling was done by an automatic mobile complex that included a navigation system with built-in high-precision GPS receiver, field computer with special software, and automatic soil sampler **(Figure 1)**. Fields were divided into basic soil sampling areas of 4 ha (200 m x 200 m) and the automatic soil sampler, moving diagonally, took 10 soil samples (0 to 30 cm depth) from each basic area. These 10 soil samples were mixed and one soil sample was prepared for the basic area and then used in soil fertility tests (with the traditional approach, one mixed soil sample is taken from the area of 25 to 40 ha). As a result, selected fields, depending on field acreage, were characterized by 10 to 30 soil samples (number of observations).

Table 1 shows results of soil fertility analysis of the agricultural enterprise's fields, including mean, confidence interval, coefficient of variation, and number of samples used in the analysis. According to these data, available P and K content in the soil were found to be the most variable parameters. The coefficients of variation for available P ranged from 16% to 51% and for available K, from 18% to 37%. Soil humus content had medium variability (7 to 15%), and the lowest variability was revealed for soil pH (2 to 5%). Thus, this study indicated considerable variability in soil fertility characteristics of chernozemic soil, particularly for available P and K, even on leveled fields of this advanced agricultural enterprise. Variable rate fertilizer application, hence, should be considered as an important method for making soil fertility distribution more uniform. According to recent estimates, variable rate fertilizer application in current economic conditions in Russia may be reasonable if spatial variability in the content of soil nutrients is about 20% or more (Afanasyev, 2010).

Using GIS software, soil fertility properties from the basic areas were interpolated to the whole field, to reveal the spatial heterogeneity of soil nutrients and create spatial distribution maps showing zones with the same level of nutrient content **(Figure 2)**. In this study, final maps indicate 20 zones (the number of zones is adjusted) over the field for each soil parameter. Such a detailed mapping of soil nutrient content is required for calculating fertilizer application rates for soil management zones with different fertility status. Calculation of fertilizer rate based on expected crop yield is done using software with a built-in equation editor, taking into consideration soil nutrient content of basic areas. Fertilizer variable rate application maps were developed for each basic area over the field, but soil management zones have a square form sized

Abbreviations and notes: GPS = global positioning system; GIS = geographic information system; N = nitrogen; P = phosphorus; K = potassium; RUB = Russian Rubles (approx. 30.6 RUB/USD).

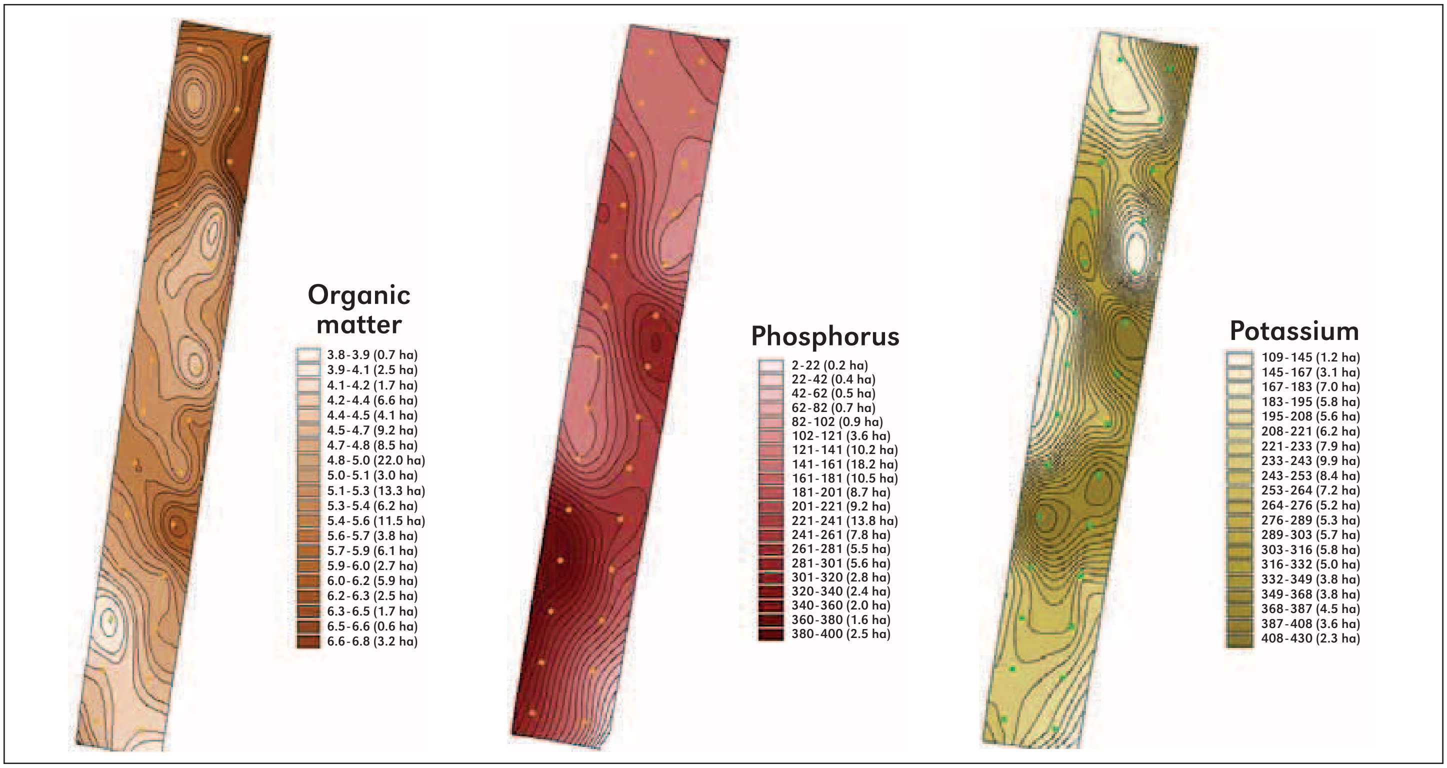

Figure 2. Distribution of organic matter and available P and K (as P_2O_5 and K_2O, respectively) at experimental field number 3 (20 zones) of the agricultural enterprise in Stavropol District, Samara Oblast.

Table 1. Soil fertility analysis of agricultural enterprise's fields in Stavropol District of Samara Oblast, including mean, confidence interval, coefficient of variation, and number of samples used in the analysis (Tsirulev et al., 2008).

	----- Field number -----									
Soil fertility parameters	1	2	3	4	5	6	7	8	9	10
Organic Matter[1], %	4.63	4.78	5.32	5.05	5.06	5.27	4.73	4.62	4.44	4.33
	4.43-4.83	4.36-5.20	4.68-5.96	4.81-5.29	4.54-5.58	4.89-5.65	4.47-4.99	4.45-4.79	4.12-4.76	4.12-4.54
	8.8	8.9	15.1	6.9	12.3	7.7	9.5	7.0	10.6	7.2
Available P (as P_2O_5), ppm	168	153	188	174	190	225	281	226	154	116
High = 46 to 60 ppm	144-192	73-232	140-237	156-191	165-214	157-293	248-313	202-250	123-185	84-148
	27.0	51.4	32.9	15.9	16.1	31.7	20.5	18.5	30.3	42.5
Available K (as K_2O), ppm	228	215	268	286	288	331	363	261	210	237
High = 401 to 600 ppm	185-270	177-254	199-337	220-352	203-374	215-447	300-426	220-303	176-242	184-290
	35.2	17.8	32.8	35.7	36.4	36.9	31.1	27.3	24.5	34.8
pH (H_2O)	6.73	6.97	6.61	6.13	6.19	6.76	6.56	6.75	7.02	7.03
	6.59-6.87	6.78-7.16	6.46-6.76	6.01-6.25	5.95-6.43	6.54-6.98	6.41-6.71	6.63-6.87	6.90-7.14	6.91-7.15
	4.02	2.54	3.00	3.19	5.12	3.64	3.95	2.97	2.34	2.51
n	30	10	15	21	14	11	27	25	20	21

[1] Upper row – mean; middle row – minimum-maximum values (confidence interval); bottom row – coefficient of variation, %.

according to the coverage of a variable rate fertilizer spreader (polygons converted to blocks).

A short-term, on-farm research experiment was conducted in the same agricultural enterprise to investigate the benefits of variable rate fertilizer application to spring wheat based on measurement of spatial variability in available P and K content in the soil (Tsirulev, 2008). The experiment consisted of five treatments: 1) extensive crop management approach without fertilizer use (control), 2) ordinary technology (average fertilizer practice, without soil testing), 3) ordinary technology with GPS navigation (to monitor and control agricultural machinery operations in the field), 4) intensive technology (fertilizer rates calculated using the balance method based on expected wheat yield and the average available P and K content in the soil measured with the traditional soil sampling procedure), 5) intensive technology with GPS navigation and variable rate fertilizer application.

The lowest grain yield of spring wheat was obtained from the control treatment with extensive crop management technology and zero fertilizer use – 1.35 t/ha **(Figure 3)**. Other treatments gave yield increases of 0.42 to 0.70 t/ha above the control. The use of GPS navigation and variable rate fertilizer

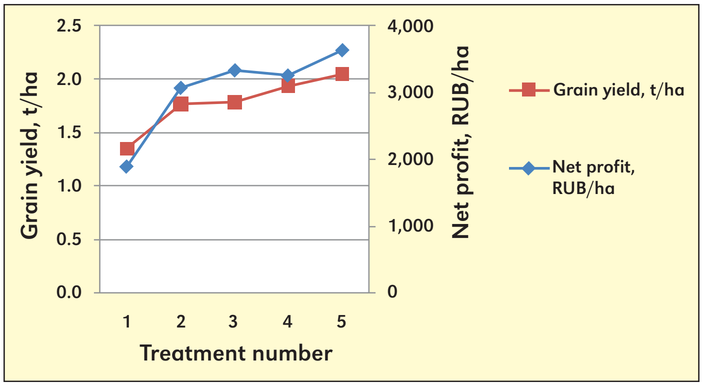

Figure 3. Grain yield of spring wheat and net profit as affected by crop management technology in on-farm research experiment conducted in 2007 at the agricultural enterprise's field in Stavropol District, Samara Oblast (Tsirulev, 2008). Treatments:

1 – Extensive technology without fertilizer use (control)
2 – Ordinary technology (average fertilizer practice)
3 – Ordinary technology with GPS navigation
4 – Intensive technology (fertilizer rates calculated using the balance method)
5 – Intensive technology with GPS navigation and variable rate fertilizer application

application in the 5th treatment were the most efficient in increasing grain yield of spring wheat (to 2.05 t/ha) compared to other technologies studied in the experiment. The benefit of crop management under precision agriculture technologies was uniform (without gaps and overlaps) application of mineral fertilizers and plant protection inputs on the experimental field. At the same time, areas with lodging of spring wheat were observed in plots receiving the treatment with intensive crop management technology, but without GPS navigation. This was because of overlap in applying broadcast N fertilizer **(Figure 4)**.

Net profit was highest for the 5th treatment (3,638 RUB/ha) where precision agriculture approaches were used, and exceeded by 11% the net profit for the 4th treatment (3,264 RUB/ha) when fertilizer rates were calculated using the balance method based on the average available P and K content in the soil **(Figure 3)**. The measurement of spatial variability in available P and K indicated areas with high or very high levels for both nutrients, which for the 5th treatment did not require P and K fertilizer application according to the standard soil fertility classes. Thus, fertilizer expenses decreased by 9%

Figure 4. Lodging of spring wheat in treatment No. 4 under intensive technology without GPS navigation. Overlap in applying broadcast N fertilizer resulted in lodging.

(from 1,552 to 1,411 RUB/ha) compared to the 4th treatment where fertilizer rates were calculated by the balance method based on the analysis of a mixed soil sample from a large area.

It may be concluded, therefore, that measurement of the spatial heterogeneity of soil fertility factors enabled more precise agrochemical analysis of arable fields compared to the routine approach widely used in soil fertility surveys. Variable rate fertilizer application, moreover, considerably increased the efficiency of mineral fertilizer use. It is important to note that the application of fertilizers at average rates based on the traditional soil sampling method may result in both under- and over-fertilization on some parts of the field. The latter factor may have a negative impact on the environment. BC

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IPNI Introduces "Nutrient Source Specifics" Series

IPNI has introduced a new series of one-page, condensed fact sheets highlighting common fertilizers and nutrient sources in modern agriculture. The series is called "Nutrient Source Specifics".

"These topics offer brief information about the production, agricultural use, management practices, and chemical properties of common fertilizer materials," said IPNI President Dr. Terry L. Roberts. "One of our thematic work groups saw the need for this kind of information and we believe the series format will be useful in providing a quick reference library as we add to it. However, we also encourage individuals to consult with local experts regarding specific nutrient use."

One of the goals of IPNI is to provide science-based plant nutrient and fertilizer information to a wide range of audiences.

Written by IPNI scientific staff, Nutrient Source Specifics topics are primarily for educational use by a non-technical audience. The list of topics currently consists of: 1) urea; 2) polyphosphate; 3) potassium chloride; 4) compound fertilizer; 5) potassium sulfate; 6) potassium magnesium sulfate: langbeinite; 7) urea-ammonium nitrate; 8) thio sulfate; 9) monoammonium phosphate (MAP); and 10) ammonia.

The series will be available as individual PDF files at the IPNI website: >www.ipni.net/specifics<.

Getting Started with Precision Agriculture

By Amy Winstead and John Fulton

Precision agriculture (PA) technologies, once thought to be only for large-scale producers focused on intensive management, are readily available and affordable for a wide variety of agricultural operations. Interest in adoption and implementation of PA technology has rapidly increased in the USA, including the demand for high-level GPS [real-time kinematic (RTK)] accuracy, precise applications of inputs, and solutions for information management.

Precision technologies have not always been economical for small to medium-sized farming operations. However, with PA equipment becoming less expensive, tools such as guidance systems, yield monitors, and variable-rate fertilizer applicators may now contribute to savings for nearly all growers. The costs of inputs and commodity prices considerably increase the risk of making the wrong management decision. Thus, even small farms can profit from using technologies that improve production efficiency.

A survey of Alabama farmers was conducted in 2009 to evaluate current PA adoption and intended adoption of various precision farming technologies **(Figure 1)**. According to the survey results, 58% of respondents are using light bar guidance technology, 34% currently utilize assisted steering technology, and 31% use RTK guidance on their farms. Also, 86% of respondents either currently utilize or intend to implement automatic swath control technology. Yield monitor adoption was separated into three classes: currently using a yield monitor (43%), intending to use a yield monitor in the future (33%), and not intending to use a yield monitor (24%). Survey results indicated significant intended adoption by producers. Fifty-one percent of repondents intend to adopt variable-rate technology in the next 2 years, compared to 24% who are currently using the technology.

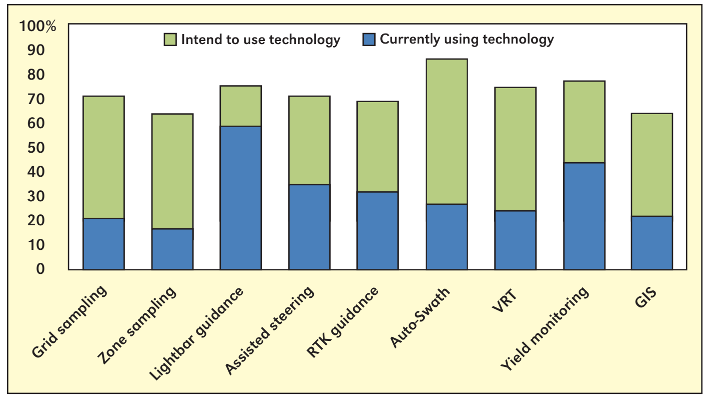

Figure 1. Results of 2009-2010 Alabama Precision Ag Adoption Survey.

A yield monitor with GPS is used on a grain combine to geographically map yield data across the field. Yield maps provide a 'report card' for a producer by providing feedback about crop production and management.

Illustration of a sprayer equipped with automatic section control technology which turns boom sections or individual nozzles on/off as the sprayer moves through the field. The sprayer uses guidance technology to minimize overlap and skips.

Abbreviations and notes: GPS = global positioning system; N = nitrogen.

One technology that farmers are readily adopting in Alabama and across the USA is automatic section control technology (ASC). This technology was initially available for use on sprayers, but is now also being used on planters, spreaders, and other application equipment by PA practitioners.

The premise of this technology is that the operator can turn sections of application equipment off in areas where application has already occurred or in un-targeted areas such as environmentally sensitive grassed waterways. A recent study at Auburn University found that ASC can reduce input usage by 1% to 10% per pass across the field; these savings are a result of reduced overlap at headlands and within point rows. In return, farmers can expect annual savings of between $1.50 to $25.00/A for this technology, depending on crop, management, and field shape and size. On average, the study suggested a 4.3% savings on inputs for a farm operation when using only ASC… with a payback period of less than 2 years for most application equipment (sprayers, planters, and N side-dress units provided the greatest returns). However, even larger savings can be observed if ASC is used in conjunction with a guidance system, which can further reduce overlap and input usage, especially from adjacent passes of application equipment (Troesch et al., 2010). Another study suggested guidance systems can, on average, save an additional 12% on inputs and 15% to 30% overall savings when using both ASC and guidance systems together.

The Alabama survey documented significant future adoption of auto-guidance systems by Alabama producers; 37% of survey respondents intend to adopt the technology in the next 2 years compared to the 31% currently using it. Producers have cited reduced concentration needed during driving (which leads to less fatigue and an increased ability to focus on other

The crop is planted using auto-guidance technology.

tasks) as a major reason for adopting this technology. While the adoption of yield monitors coupled with GPS has been low in Alabama, growers are quickly starting to understand the advantage of yield maps to not only evaluate current and new management practices, but also as a data source for development of site-specific management strategies (i.e. management zones, variable-rate seeding, nutrient prescription maps, etc.). The survey also suggested that growers view grid and zone soil sampling and variable-rate application technology as having significant potential to provide cost savings and yield benefits.

Considerations for Getting Started

With the increasing interest and predicted adoption of PA technologies, one of the most frequent questions from producers is: "How do I get started using precision agriculture technology?" The following points serve as guidelines for Certified Crop Advisers, consultants, and university extension and industry personnel to use to educate and assist growers in choosing the most appropriate PA technologies for their operations. These guidelines were developed based on grower survey results and personal communications with PA dealers and both long- and short-term users of PA.

Table 1. Guidelines for getting started in precision agriculture.

- Establish a clear objective when adopting PA technologies and/or practices.
- Select technologies that can be used for multiple operations.
- Identify tools that can be easily moved among different pieces of farm equipment.
- Choose technologies that will be compatible with current and future farm equipment.
- Ensure PA equipment can be easily and inexpensively upgraded.
- Determine the level of GPS accuracy and year-to-year repeatability required for specific operations.
- Ensure that recorded data will be easily transferrable.
- Determine the future needs for the farming operation and how current PA technologies can play a role.
- Understand the time requirement for adoption of PA systems and determine a timeline for implementation.
- Identify the training, support, and service tools that are available for new products being considered.

First, there should be a clear objective in mind when adopting PA technologies and/or practices. Just as PA allows growers to address site-specific production issues, the reason for getting into precision agriculture will also vary from grower to grower. Is the goal to be more efficient with inputs? Better on-farm record keeping? Are there needed management changes that require additional knowledge about the farm? Failing to establish a well-defined objective can be costly and counter-productive.

An example of a precision ag display mounted inside the cab, providing real-time performance parameters to the operator and the ability to collect various data.

Users of PA technologies consistently stress the importance of selecting products that are compatible with multiple operations. Utilizing components such as monitors, receivers, antennas, and controllers across various applications and equipment can help to spread the cost of PA technology. For example, a PA display monitor can be purchased for guidance. It can be moved to harvest equipment for yield monitoring and then returned to the tractor and used for variable rate fertilizer applications.

An important consideration regarding compatibility is whether the technology is easy to move between farm equipment. If a guidance system being used in a spreader truck to apply fertilizer needs to be moved to a sprayer, will additional specific wiring harnesses or cables be needed for each piece of farm equipment? Also, consider whether the technology will be compatible with future farm equipment. Precision farming tools can be proprietary to farm equipment. If farm equipment upgrades or trades are planned in the future, current PA equipment should be able to be used on the new equipment. If upgrades to PA equipment will be needed, consider the ease and cost. For example, many entry-level guidance systems can be upgraded from utilizing WAAS GPS correction (sub-meter accuracy) to a paid subscription (decimeter-level accuracy) or RTK correction (centimeter-level accuracy). Additional features such as automatic swath control or auto-guidance can be added on.

A major point of consideration that new users of PA technologies need to learn is the level of GPS accuracy and repeatability required for a specific operation. Different levels of GPS correction are more appropriately suited to specific farming practices. For example, strip-tilling and planting peanuts would require centimeter-level accuracy and year-to-year repeatability to be able to plant and harvest directly on the row year after year. However, sub-meter accuracy is sufficient for running a yield monitor on a grain harvester.

While most PA systems currently on the market have the ability to record and download data, not all do. If this is a desirable feature, certain considerations are needed. The format that data are recorded and exported in varies among PA equipment so it is important to ensure that the data can be downloaded in a format that will be accessible by the user. For example, if an Agricultural Geographic Information System (AgGIS) is not used for data management, then a PA system that can export data as a Portable Document Format (.pdf) or Rich Text Format (.rtf) file would be desirable to allow the user the option of viewing collected data.

It is very important to consider both current and future needs for the farming operation and the role that PA technologies can play. Developing long-term PA implementation plans can help with purchasing decisions. Collected data should always be kept even if it is not currently being utilized in the farm management program. Elevation data collected using an RTK system and yield data are examples of data that can be collected and then used in the future to create management zones or prescription maps for variable rate applications.

Finally, potential users of PA technologies need to be aware of the time requirement for adoption of PA systems and determine a timeline for implementation. There is a learning curve associated with PA technology and installations can often take longer than anticipated. In addition, even the most "operator-friendly" tool will require an adjustment period. An adoption and implementation timeline might need to extend over a few growing seasons, not just to work out the kinks and get comfortable with the new tools, but to fully establish the system needed to obtain the desired results. Successful adoption of PA technologies will in many cases be more of an evolving process rather than a quick-fix that will show immediate results. The associated learning curves for PA adoption make it important to identify the training, support, and service tools that are available for new products during the selection process. Most experienced PA users agree that service for PA equipment is one of the most important things to consider when making a new purchase.

Overall, there is no right or wrong approach to adopting and implementing PA technology. Potential users of PA should be encouraged to conduct on-farm studies to evaluate which PA practices will provide the best return for their operation. While PA technologies and practices can appear overwhelming at first, it is important to remind newcomers to take the process slow and in steps. Guidance systems and ASC provide quick, tangible benefits to farmers while other technologies and site-specific management approaches can provide benefits, but should be evaluated over several years. It can take time for practitioners to fully start to experience savings or increased profit from precision agriculture, especially precision-based nutrient management practices. BC

For more on precision agriculture technologies, visit the Alabama Precision Ag website: www.AlabamaPrecisonAgOnline.com.

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Reference

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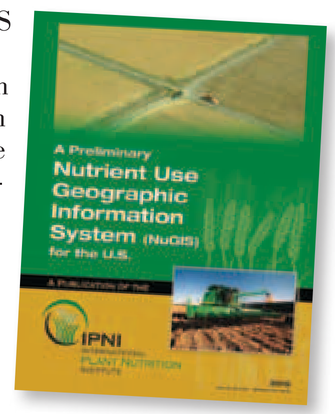
IPNI Introduces NuGIS – A New Tool for Evaluation of Nutrient Use and Balance in the U.S.

IPNI has unveiled a new publication titled *A Preliminary Nutrient Use Geographic Information System (NuGIS)* for the U.S., along with an interactive on-line interface.

"For the past couple of years, IPNI scientific staff and other cooperators have been working on a rigorous GIS-based model for assessing nutrient balance and balance trends in the U.S., termed 'NuGIS'. This project is part of our responsibility for understanding the nutrient status of cropping systems and as a complement to our periodic inventorying of soil fertility levels in the U.S.," said IPNI President Dr. Terry Roberts.

By integrating multiple data layers to create county-level estimates of nutrient removal by crops, fertilizer applied, and manure nutrients, NuGIS offers a rather clear picture of nutrient balance for most of the contiguous 48 states, as well as temporal trends over the last 20 years. Geospatial techniques are used to migrate the county data to watersheds which allows NuGIS output to be compared to the output of other natural resource models.

"IPNI sees on-going assessment of nutrient balance and nutrient use efficiency in crop production as one of its responsibilities. That assessment is one of the two primary objectives of NuGIS. The other objective is to identify weaknesses in the process of doing that assessment," explains Dr. Paul Fixen, IPNI Senior Vice President and Director of Research. He has been the leader of the NuGIS effort.



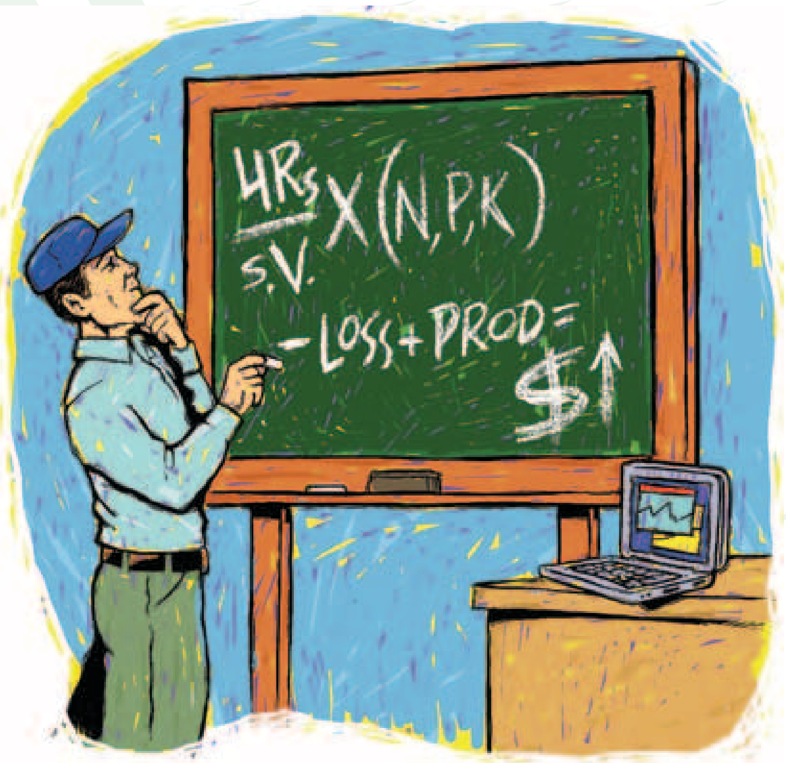
"An extensive in-depth methods section is provided in the bulletin to offer complete transparency into how the balance estimates are made and displayed. Results are shown in a combination of color maps, tables, and graphs, summarized in a 60-page publication and available on CD. The CD also contains a PowerPoint file of figures and an Excel workbook containing all balance component data at a state level. Interpretation of the results is rather limited.

A Preliminary Nutrient Use Geographic Information System (NuGIS) for the U.S., the 60-page, 8 ½ x 11 in. booklet, is available for purchase at USD 25.00 per copy, plus shipping/handling. An order form with more information plus a PDF of the complete publication are available for download at the IPNI website: >www.ipni.net/nugis<. Visitors to the website may also access the interactive on-line tool. Comments, suggestions, or questions may be sent by e-mail to: >nugis@ipni.net<.

The Role of Spatial Variability in Nutrient Management

A thorough understanding of spatial variability in agricultural fields can influence many aspects of nutrient management. Whether it is what nutrient source to apply, what rate to use, when to make the fertilizer application, or what placement method to employ, understanding spatial variability can help growers, advisers, industry, and policymakers contribute to more efficient and effective fertilizer management.

Understanding spatial variability can help guide technology development. Yield monitors, mapping software, and variable-rate fertilizer applicators were all developed based on the knowledge that not all areas of a field possess the same yield potential and they often don't have the same nutrient requirement. Precision agriculture technology currently provides growers and advisers the tools needed to identify, diagnose, and treat spatial variability in fields. However, continued investigation into the effects of variability on fertilizer management will improve our understanding of the situation and will lead to refined approaches and the development of new technologies needed to meet the challenges.



By applying fertilizer only where it is needed in the field, productivity and profitability can be improved. Most standard nutrient recommendation strategies involve determining an average fertilizer need for the field and a single rate is applied to the entire field. Using this strategy, some areas of the field receive more than the optimum amount of fertilizer while other areas may not be receiving enough. Applying fertilizer in this manner results in lower productivity and profitability due to missing out on additional yield in the parts of the field that are under-fertilized and further reduced profitability where fertilizer is over-applied. Understanding how fertilizer requirement varies spatially in a field will allow the grower to use variable-rate application technology to redistribute fertilizer accordingly throughout the field.

Considering spatial variability when making fertilizer management decisions can also improve environmental quality and cropping system sustainability. Using spatial information to better match crop requirement with nutrient supply will result in less fertilizer remaining in the field with the potential to negatively impact the environment through various loss mechanisms. Understanding the sources and influence of spatial variables such as soil type, water and nutrient holding capacity, slope, topsoil thickness, etc., can aid growers and advisers in selecting appropriate best management practices (BMPs) for each field that will support the long-term health of the cropping system.

Understanding spatial variability is critical when following 4R nutrient stewardship. The basis of 4R nutrient stewardship is selecting the "right" fertilizer source and applying it at the right rate, at the right time in the growing season, and in the right place. What is "right", however, depends on many site-specific factors, including the degree of spatial variability a particular grower might be dealing with. Failing to consider spatial variability when making nutrient management decisions can result in what appears to be the "right" choice for the field being quite "wrong" in many areas of that field. Following 4R nutrient stewardship at the appropriate spatial scale can lead to improved fertilizer efficiency and effectiveness, increased productivity and profitability, and lower the risk of environmental impacts due to misapplication of fertilizer.

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