BETTER CROPS
WITH PLANT FOOD

2014 Number 3

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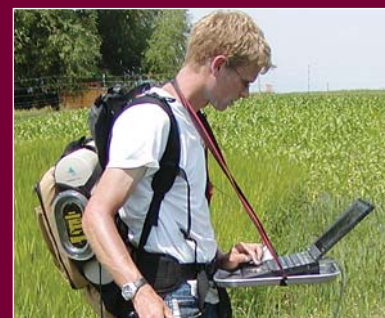
Keys Factors for Improving Potassium Uptake and Use

Recognizing the Value of Crop Straw

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IPNI

BETTER CROPS
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Note to Readers: Articles which appear in this issue of *Better Crops with Plant Food* can be found at: >**www.ipni.net/bettercrops**<

IPNI Board of Directors Elects New Officers

New officers of the Board of Directors of the International Plant Nutrition Institute (IPNI) were elected in May 2014. The election took place at the IPNI Board meeting held in Sydney, Australia, in conjunction with the 82nd Annual Conference of the International Fertilizer Industry Association (IFA).

Mostafa Terrab, Ph.D., Chairman and Chief Executive Officer, OCP Group, Morocco, is the new Chairman of the IPNI Board for a two-year term. Mr. Jim T. Prokopanko, President and Chief Executive Officer of The Mosaic Company, Plymouth, Minneapolis, was elected Vice Chairman of the IPNI Board. Mr. Oleg Petrov, Director, Sales and Marketing, Uralkali, Moscow, Russia, was elected Chair of the Finance Committee.

Mr. Stephen R. Wilson, who retired as Chairman, President and Chief Executive Officer of CF Industries Holdings Inc. as of January 1, 2014, also concluded his term as Chairman of the

Dr. Mostafa Terrab, Chairman of the IPNI Board

Mr. Jim T. Prokopanko, Vice Chairman of the IPNI Board

Mr. Oleg Petrov, Chair of the IPNI Finance Committee

IPNI Board of Directors and was recognized for outstanding leadership and service in his role. **BC**

Annual IPNI Program Report is Now Available

IPNI has released its annual Program Report for 2014 titled **4Rs: From Theory to Practice**.

The concept of 4Rs—applying the right source of plant nutrient, at the right rate, at the right time, and in the right place—as a means of sustainable nutrient management was developed over many years as the fertilizer industry worked closely with our colleagues in the scientific community.

What IPNI did in 2007 was re-introduce the idea of 4Rs to the global fertilizer industry at an International Fertilizer Industry Association workshop on fertilizer best management practices (BMPs) and suggest a context of how 4Rs can be applied globally.

Agronomists know what yield to expect with a given rate of fertilizer, how split applications, placement, or balanced fertilization can impact efficiency, the relative availability of one fertilizer source compared to another, and much more related to these BMPs. These fertilizer BMPs have and are routinely used and put into practice.

But what happens when all four rights are implemented together … what are the interactions? We can make educated guesses based on past experiences and we can theorize what should happen, but we can't always give a definitive answer about what will happen. Society wants to know if 4R Nutrient Stewardship is implemented, what is the measurable or documented impact going to be on our water quality, greenhouse gas emissions, or air quality? What is the impact on fertilizer use efficiency, on food production, on farm economics? What are the social impacts? These are the types of questions we will need to answer. What are the metrics or performance we should be measuring to answer these questions?
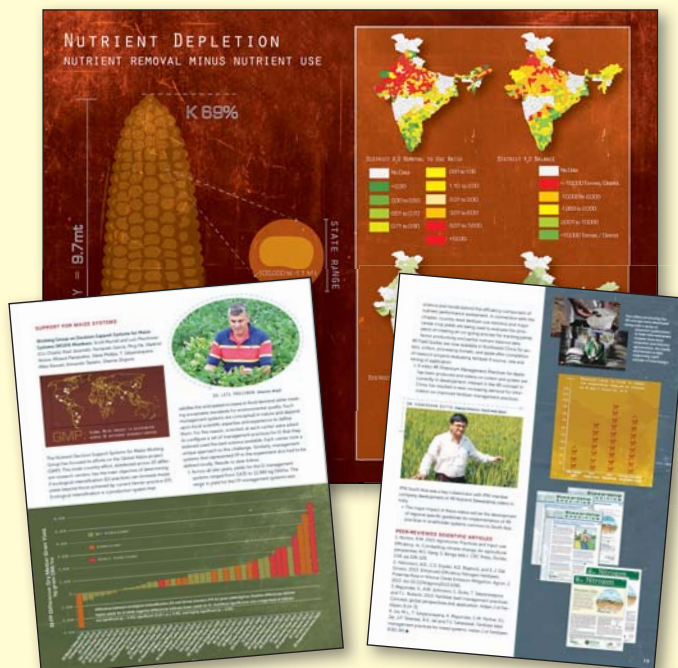
As 4R Nutrient Stewardship is being discussed, evaluated, adopted, and being looked at as a solution to environmental concerns related to nutrient use, it's now time to move from theoretical implementation to practice. This is the phase IPNI is entering … as 4Rs become implemented and put into practice; IPNI needs to show their application is the best way to manage plant nutrients sustainably.

This year's report provides an update on the progress and plans as 4Rs go from theory to practice, plus much more. 4Rs are a common thread of all IPNI agronomic programs, but these programs are diverse and include other activities.

This report is available from the IPNI website: http://www/ipni/net/programreport. **BC**
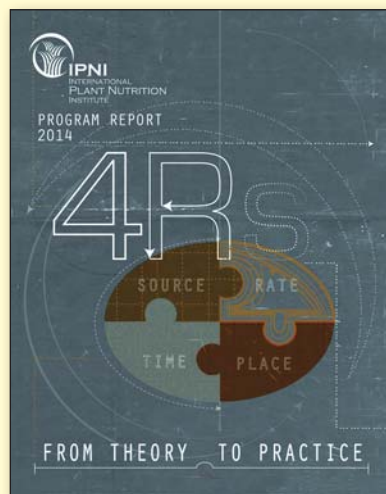
Precision Agriculture: Supporting Global Food Security

By Steve Phillips

The global population is expected to surpass 9 billion people by 2050, and food security challenges are at the forefront of every discussion regarding agricultural production. According to most estimates, food production will have to increase 50 to 70% to meet global demand. The fertilizer industry will need to be a world leader in meeting this challenge as fertilizers are currently responsible for 50% of food production and will likely be even more important in the future. Success can be best achieved using the evolving tools, technologies and information management strategies found in precision agriculture (PA).

No single agricultural technology or farming practice can be viewed as a "silver bullet" for increasing food security, but rather the "stacking" of all technologies is where the real benefit lies. Combining PA, existing nutrient management strategies (e.g., 4R Nutrient Management, Integrated Soil Fertility Management) and effective combinations of other high priority technologies (i.e., no-till farming, improved crop protection, irrigation) have been reported to have the potential to result in as much as 67% increases in global crop yields (Rosegrant et al., 2014).

The historical corn yield trend in the U.S. is an example of how stacking technologies can lead to sustained yield increases. From 1965 to 2013, U.S. corn grain yields have steadily increased by 1.8 bu/A/yr. However, underlying this trend is a stream of technological innovations that include improved soil management and fertility, genetic improvements, integrated pest management, and precision technologies (**Figure 1**). The question is what will be the next innovative practice, not just for U.S. corn, but for food production worldwide, that will increase yields? A good guess would be PA. Precision agriculture is a rapidly growing industry and more and more farmers are taking advantage of the technologies to more effectively manage their operations. It's important to note that PA is much more than tools and technologies. It is better defined as whole farm management focused on maximizing the use of information to make decisions and optimizing inputs and preserving resources. Precision agriculture has the potential to create more knowledgeable farmers than ever before.

Engaging the Mobile Device

One of the ways farmers are becoming more knowledgeable is through the use of mobile device technology. The trending popularity in mobile device technology for agriculture has increased markedly over the past couple of years and is projected to continue, with an expected 1.25 billion people owning a mobile device (smartphone or tablet) by the end of 2014. There are many reasons why the use of mobile device technologies in agriculture is growing rapidly. The most obvious reason is that many people already have one. Anytime a tool that users are already familiar with can be used to enhance

Abbreviations and Notes: N = nitrogen; P = phosphorus; K = potassium.
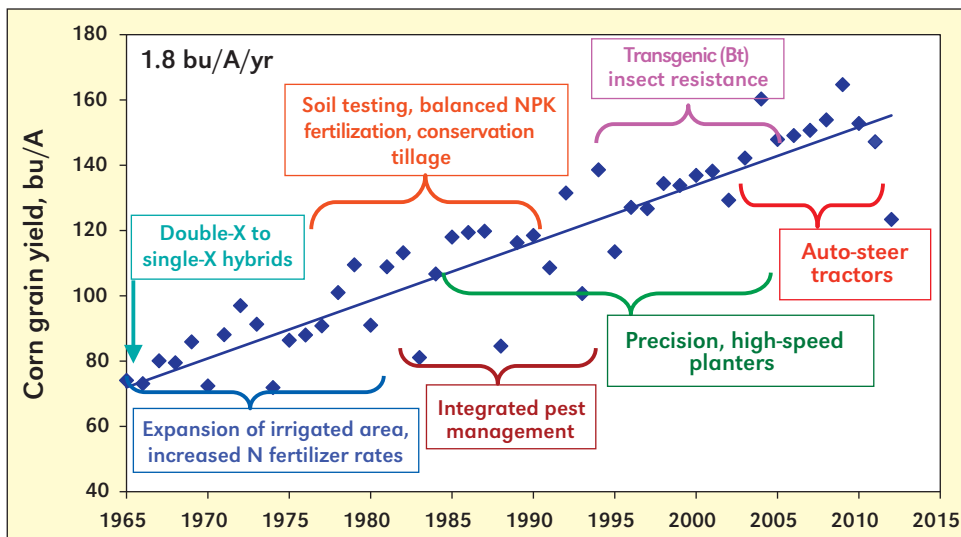
Figure 1. U.S. average corn yields (1965 to 2012) and the stream of technological advancements supporting productivity (modified with permission. Cassman et al., 2006).

farm management, adoption will be rapid. Another driver for adoption is the recent explosion in agricultural applications (apps) for mobile devices that make it possible for users to have access to more information than ever before. Functions and uses of various agricultural apps include news, weather, and market updates, identification tools for weeds, pests, and nutrient deficiencies, input calculators for seed, chemicals, and fertilizer, and comprehensive scouting tools.

Tackling Variability

For decades, one of the key drivers for the development and adoption of PA technologies has been nutrient management. Current estimates are that approximately 70% of fertilizer dealers and ag. retailers in the Midwest U.S. are equipped to provide variable rates of fertilizer and lime, with the numbers expected to reach 80% by 2016 (Holland et al., 2013). Seventy percent also offer GPS-based soil sampling, while nearly 50% will provide satellite or other aerial imagery for management zone delineation. Redistributing fertilizers based on soil and crop variability optimizes production by minimizing over- and under-application of nutrients. Most variable-rate nutrient applications are map-based, relying on either a grid or zone soil sampling strategy. So rather than a single fertilizer recommendation for the entire field, as would be the case using a composite soil sample, multiple recommendations are made within the field according to the fertility needs of the various management zones. Another map-based approach is to use yield maps to make variable-rate fertilizer applications based on nutrient removal estimates for the previous crop. This nutrient balancing approach can be an effective method for

maintenance of soil nutrients, but is generally not preferred over a soil-test based approach.

Another technology used to make variable-rate nutrient applications, particularly for N, is crop canopy sensors. The basic function of all forms of these sensors is to measure reflected light from the crop and use that information to determine the crop nutrient requirements by utilizing N rate algorithms that incorporate a variety of site-specific information depending on the sensor system being used. The reliance on these algorithms has resulted in slow commercial adoption rates despite well-documented success in both small- and large-scale research and demonstration studies. The use of crop sensors has begun to increase more rapidly in the past few years, particularly in the U.S. and Europe. Reasons for the increase now as opposed to when sensors first became commercially available a decade ago have to do with various factors. First, the N rate algorithms are well established and cover a variety of crops and geographies. Second, is the opportunity to utilize the tool for more applications including weed pressure mapping and variable-rate herbicide sprays, variable-rate plant growth regulator and defoliant applications, and estimating disease and insect stress and damage spatially throughout the field.

One of the misconceptions about PA is that it is only an option for the large-scale, high-profitability farming systems found in developed nations. In reality, spatial and temporal variability exists in smallholder systems and allowing these factors to contribute to the mismanagement of resources creates an even greater risk to these producers. The ability to incorporate spatial and temporal information into the decision-making process in the developing world is of tremendous value, possibly even more so than in developed nations. Several precision nutrient management strategies exist and are being used successfully in smallholder systems including leaf color charts, omission plots, handheld crop sensors, and web-based decision support software packages.

Another practice rapidly gaining popularity is variable hybrid planting. Just as in the case of spatial variability of soil nutrients, not all areas of the field have the same production potential with regard to hybrid or variety performance. The most popular hybrids are often the highest yielding in seed trials. However, these trials are typically conducted under optimum conditions and many of the high performers have very low tolerance for less than optimum conditions that are found spatially distributed in many agricultural fields. Other hybrids that don't have as high of a yield potential are better suited to handle these stressed conditions. So in practice, the higher yielding hybrid will be planted in the best parts of the field, while the more durable, lower yielding hybrid will be planted in the problem areas. Varying seeding rates based on spatial variability has also shown to be a profitable practice. Zones of a field with low production potential often do not have the capacity to support the seeding rates recommended for optimum yield. In these areas, seeding rates can be reduced to more closely match the yield potential in that area and increase whole farm profitability.

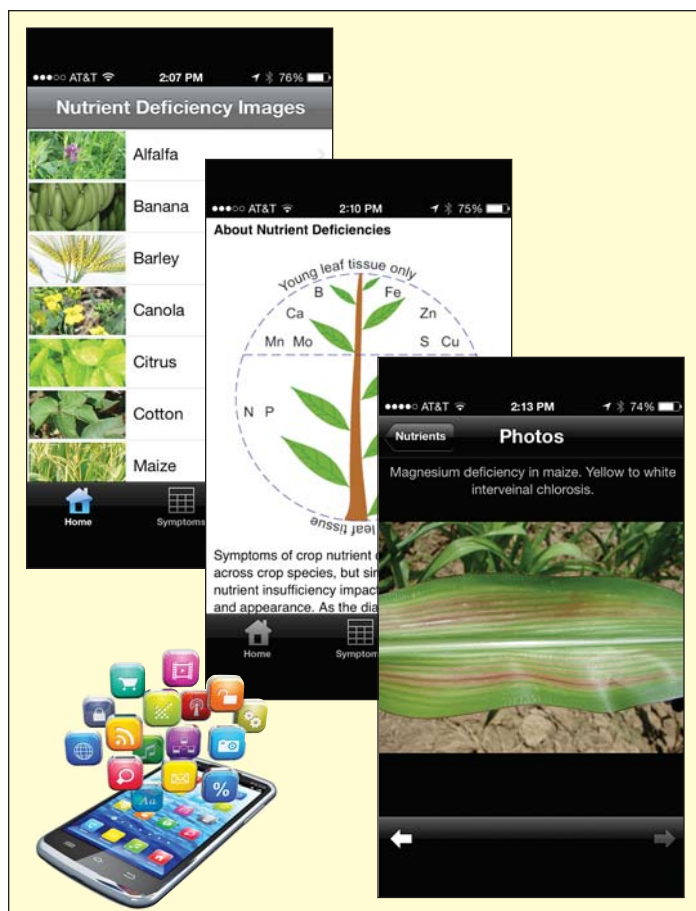Water is yet another agricultural input that is more commonly being managed using variable-rate techniques. Irrigation amounts, timings, and spatial distribution can be effectively managed using precision technologies. Variable water requirements can be determined using soil moisture sensors or

Adoption of agricultural applications within mobile device technology have the advantage of familiarity and accessibility.

weather and plant-based evapotranspiration models. Irrigation timing becomes more precise by using real-time information and variable-rate distribution systems, (whether pivot, lateral, or drip) and result in more efficient use of water resources. Precision drainage can also be used to control soil profile moisture throughout the growing season. Keeping with the increasing trend of agricultural application technologies, water management is more commonly being done through mobile device platforms. One example of an irrigation-scheduling app uses real-time weather and crop development data to estimate moisture deficits and farmers are notified of a need to irrigate with a recommended amount via text message.

Improving Technologies

The most rapidly growing adoption trends in U.S. PA over the past five years involve data integration and equipment technologies. The increasing availability and capacity of wireless data transfer has resulted in easier integration of outside data such as weather, higher utilization of GPS-based logistics for equipment management, and overall improvements in decision-making. The process of transforming data into information that can lead to a knowledgeable management decision is faster and easier than ever before. Compatibility of tools has also increased markedly over the past few years resulting in very rapid adoption of equipment technologies, specifically automated guidance and sprayer boom section controls.

GPS-based manual guidance technologies have been popular for a decade or so, but in the past four to five years the use of automated guidance has surged tremendously. While manual

Decision support tools integrate the numerous site factors used in making decisions about nutrient management practices.

systems still relied on the operator to guide the equipment along the GPS-targeted path, automated systems have taken the controls out of the hands of the farmer and use mechanical navigation. Automated guidance results in greater accuracy of each pass across the field, as well as increased operator comfort. Also adding to the accuracy and precision of agricultural input placement is automatic section control (ASC) technology. Automatic section control is not a variable-rate approach, but rather a technology that allows multiple sections of the implement to be turned on or off as needed. This technology allows the operator to significantly minimize overlap and skips as the application is made. Whether applying chemicals or fertilizers, the ability to precisely target applications has a positive effect not only on profitability, but also on environmental quality by minimizing over-application and potential off-site movement. Using ASC on planters also has economic value by optimizing plant population in the field by improving the precision of row spacing and eliminating double seeding.

Looking to the future of PA technologies, one that is generating a great deal of interest among numerous stakeholders is the use of unmanned aerial vehicles (UAVs). UAVs, or drones, are small, self-propelled aircraft that can be used to collect high-resolution data from fields rapidly and inexpensively. The aircraft is equipped with a data collection device ranging from something as simple as a digital camera to very high-tech multi-spectral and thermal imaging sensors. There are several benefits to using UAVs; however, much more research is needed before this technology finds its way into commercial use. One of the major obstacles to adoption will be the rules and regulations surrounding their use. Despite the possible challenges moving this technology into mainstream agriculture, there is as much excitement surrounding UAVs as anything in PA right now.

Summary

Meeting the food production challenges for a growing population is a daunting, but not impossible task. It will require focus, cooperation and a combining of technologies across several disciplines of agriculture and society. Implementing PA technologies within the context of 4R Nutrient Stewardship—supporting the fundamental practices of applying the right nutrient source at the right rate, at the right time, and in the right place—is an efficient and effective way to help meet the environmental, economic and social goals of sustainable agricultural systems. BC

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Fine Tuning Remote Sensing Technologies for Nitrogen Application in Semi-Arid Cereal Crops

By Tom Jensen

Sensor-based technologies have been researched and developed to the point that commercial technologies are now commonly used on the farm. Recent research focused on small grain systems of the semi-arid region of U.S. northwest indicates that refinements and technological advancements are leading towards more precise options to assess crop N status in these systems and guide fertilizer applications.

The interest in precision agriculture technologies continues to grow in the semi-arid, small grain producing areas of North America. The most common practice is auto steering of farm equipment used for fertilizing, planting, and pest control applications. This has come about because of technical advances in GPS, GIS, and remote steering technologies. Another growing area of adoption is variable rate application of fertilizers, including pre-plant, at planting, and in-crop operations. A technology of special interest is remote sensing of growing crops for N content status in order to make in-crop variable rate N applications. These are on-the-go, sensing technologies that consist of active sensors mounted on liquid N fertilizer applicators. This can be used to measure aboveground crop biomass and greenness (directly related to chlorophyll content). Two such related, but with somewhat different technologies are GreenSeeker® (Trimble Navigation Limited, Sunnyvale, CA, USA) that measures Normalized Difference Vegetation Index (NDVI); and Crop Circle™ (Holland Scientific, Inc., Lincoln, NE, USA) that measures NDVI and Normalized Difference Red Edge (NDRE), and can be used to calculate some other indexes.

Cooperative research by scientists with USDA-ARS and University of Idaho in eastern Oregon, Washington and Idaho, and northern Montana has assessed the above mentioned in-crop remote sensing technologies for how well they can be used to measure crop N status for small grain cereal crops grown in these dryland and water-limited conditions regions (Eitel et al., 2008). One observed limitation of active sensors currently used on-farm—and calculated indexes used for measuring crop N status and determining supplemental N applications—is that these technologies work well when available moisture is adequate and does not limit crop growth. Their research shows that by calculating other crop indexes that reduce the influence of crop biomass, and emphasize the N status of the crop, it is possible to obtain an improved correlation between the sensed and calculated index value of crop (wheat) N status. Their initial work was done at Zadok Crop Stages 57 to 60 (i.e., late heading to early flowering). At this crop stage if additional foliar N is applied it is possible to raise the protein content of spring wheat that is deficient in N.

A calculated crop-sensed index that was found to improve the correlation to crop N status under water limited growing conditions, compared to using NDVI or NDRE, was the ratio of Modified Chlorophyll Absorption Ratio Index (MCARI) and Second Modified Triangular Vegetation Index (MTVI2) or (MCARI/MTVI2) (Eitel et al., 2007; Eitel et al., 2008). This was shown by comparing the correlated r^2 values of the indices

Abbreviations and notes: N = nitrogen; GPS = global positioning system; GIS = geographic information systems.

Active crop sensor attached to the front of a liquid N fertilizer applicator.

Table 1. Examples of coefficients of simple determination (r^2), and statistical probabilities, for the relationship between a selected spectral index, leaf area index (LAI) and relative chlorophyll meter values using a SPAD meter, or laboratory analyzed flag leaf N concentration, in various sets of experiments.

Spectral Index	Average r^2 value relationships to physically measured N status		
	SPAD relative chlorophyll content	Flag leaf N concentration	Reference of sets of experiments
NDVI	0.03 (0.025[†])	0.00 (0.229)	Eitel et al. 2007
MCARI/MTVI2	0.60 (0.001)	0.48 (0.001)	
NDVI	0.06 (0.10)	0.05 (0.14)	
GNDVI (Green NDVI)	0.02 (0.34)	0.07 (0.06)	Eitel et al. 2008
MCARI/MTVI2	0.70 (<0.01)	0.54 (<0.01)	
[†]statistical probability or p value.			

with the conventional flag leaf N status assessing methods using a Minolta Soil Plant Analysis Development (SPAD) 502 chlorophyll meter, or N content as measured using an automated dry combustion analyzer (**Table 1**). The improved r^2 values were attributed to the removal of the effect of crop top growth or leaf area index, and emphasis on leaf N status. The MCARI/MTVI2 index was also found to be robust to variation in soil color and brightness, due to different soil types, that produce different crop spectral reflectances within a N-rich reference strip.

Even though it is possible to more accurately assess leaf N status at the early heading stage of wheat, using the calculated index described above, this is only useful for foliar application for protein enhancement. Ideally it would be beneficial

Dr. Jan Eitel taking remotely sensed measurements in a field of spring wheat. Scanning green laser equipment is shown measuring early stage crop N status (bottom left). Inserted trays of different colored soils were used to measure the effect of soil background reflectance on vegetation indices used for in-season N management (right).

if the N status of a crop could be accurately assessed at an early stage of crop development (e.g., late tillering to early stem elongation). If a N deficient crop could be identified and supplemental N applied then, it would be possible to not only increase grain protein, but to effectively increase crop yield. The challenge, especially when assessing small grain cereal crops such as wheat, is that the amount of plant biomass is small at the earlier growth stages and the spectral interference reflected from soil and previous crop residues is too great to adequately estimate crop N status.

Researchers are now assessing the possible use of a green scanning laser, that can be used to assess the greenness of crop leaves, while separating out the effect of soil, previous crop residues, and leaf edges (Eitel et al., 2011). The r² values measured using this green laser scanning system ranged between 0.53 and 0.58 for regression models relating foliar N concentration to raw laser return intensity values, when used at Zadoks stage 32 (i.e., late tillering to early stem elongation). Such significant correlation at early stages of small grain cereal growth has not been possible previously using NDVI or NDRE systems, or even the MCARI/MTVI2 ratio described above, which more accurately estimated leaf N content under low moisture restrictions. The research using the green scanning laser has been limited to stationary equipment in research plots, and there will need to be further equipment develop-

ments and research done to determine if a liquid N fertilizer applicator might be equipped with this technology.

This leading edge research shows that there can be improvements in using remote sensing in small grain cereal producing areas to assess crop N status when low levels of available moisture limit crop growth and interfere with the assessment of whether or not there is an existing N deficiency. These improvements are presently restricted to supplemental foliar N applications at early crop heading for grain protein increases. New technologies such as a scanning green laser system may be developed to assess crop N status at an earlier crop growth stage such as at early stem elongation. **BC**

Acknowledgement

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Improving Potassium Acquisition and Utilization by Crop Plants

By Philip J. White

Dr. White recently highlighted some overlooked factors that influence K uptake by plants. There is considerable genetic variation between K efficiency factors among crop species.

Potassium is required for proper growth to support high yields. The nutrient is essential to the activity of many enzymes in plants including those for energy metabolism, protein synthesis and solute transport. It contributes significantly to cell turgor, especially in rapidly expanding cells, and acts as a counter cation for anion accumulation and transport processes. To fulfill its biochemical roles, K concentrations of 100 to 150 millimoles/L (3,900 to 5,900 ppm) must be present in metabolically active tissues.

Plants acquire dissolved K from the rhizosphere solution. In many agricultural soils, the K supply is insufficient to sustain the rapid growth of young plants and K fertilizers are required to maximize production.

Many definitions of "nutrient use efficiency" are found in the literature. Efficient plants have mechanisms that allow them to (1) gain more access to soil K (KUpE) or (2) utilize it more effectively for metabolic processes (KUtE). This article uses these two measures of K efficiency:

Plant K uptake efficiency (KUpE): The ratio of plant K content per unit of K fertilizer supplied. This measures the ability of plants to <u>acquire</u> K from the soil.

Plant K utilization efficiency (KUtE): The ratio of crop yield per unit plant K content. This parameter indicates the ability of a plant to <u>use</u> K for vegetative and reproductive growth.

Improvements in K efficiency can be achieved through improved management practices or by cultivating crop genotypes that acquire and/or utilize K more effectively. Some plant traits required to improve K efficiency are identified below to highlight recent insights to the genetics of KUpE and KUtE in crop plants.

Potassium acquisition is determined by its delivery to the root surface and then the speed of K uptake by roots. The primary focus is often on the K-supplying power of the soil, but considerable genetic variation exists between and within crop species in both K uptake efficiency (KUpE) and K utilization efficiency (KUtE). Future research may result in crops that use K fertilizer more efficiently. **BC**

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> **Abbreviations and Notes:** K = potassium; ppm = parts per million.

Potential mechanisms for improving potassium efficiency by plants

Potassium Utilization Efficiency (KUtE)

Increasing photosynthesis
Accelerating canopy development
Increasing canopy longevity
Increasing harvest index
Tolerating lower tissue K concentrations
Replacing K in non-essential functions
Partitioning K to metabolic cell compartments
Redistributing K from senescent to developing tissues
Redistributing K from root to shoot

Potassium Acquisition Efficiency (KUpE)

Increasing early root vigor
Increasing root biomass or root/shoot ratio
Increasing root surface area (lateral rooting, root hairs)
Increasing root length density
Improving root architecture for soil foraging
Increasing exudation of organic compounds
Increasing K uptake capacity of root cells
Increasing affinity for K of transport proteins
Increasing water uptake through transpiration
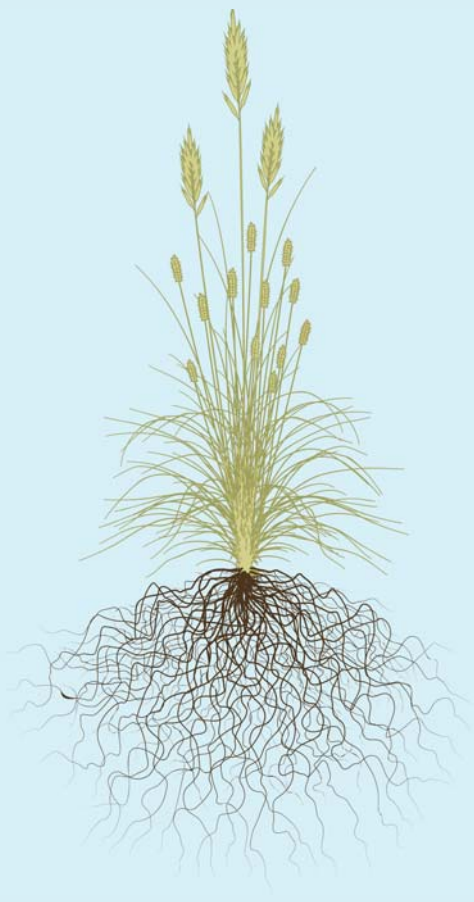
Optimizing Maize and Soybean Nutrition in Southern Russia

By Vladimir V. Nosov, Olga A. Biryukova, Alexy V. Kuprov, and Dmitry V. Bozhkov

Three years after the initiation of the IPNI Global Maize project in southern Russia, a local solution to an Ecological Intensification (EI) management system is proving to be successful model for demonstrating the potential for better yielding and high quality maize and soybean crops compared to those produced with common farm practice.

The Global Maize project of the International Plant Nutrition Institute (IPNI) is an interdisciplinary, international research effort with an overall objective of creating local Ecological Intensification practices for maize production that increase yields at a faster pace than current grower practices (Murrell, 2012). EI production systems also focus on sustainability while satisfying anticipated increases in food demand (Cassman, 1999). An EI system relies on recent research findings on plant nutrient and soil fertility management. Such important goals as putting the right fertilizer source, at the right rate, in the right place, and at the right time (4R Nutrient Stewardship) are all supported by EI management systems. Global Maize project activities began in Russia in 2011 in cooperation with the Southern Federal University (See details at http://research.ipni.net/project/IPNI-2011-RUS-GM41).

A maize-soybean rotation field experiment (A-site) was established in the District of Tselina in Rostov Oblast. The Global Maize Project designates A-sites as those comparing local EI solutions to farm fertilization practice (FP) within split-plot designs. In Tselina, nutrient management system (EI or FP) was tested across the whole plot while the level of N input was tested across the split plots (**Table 1**). This A-site has two experimental areas that allowed both maize and soybean to be grown each season. Maize and soybean were preceded in the field by winter wheat in 2010. The FP N2 treatment in maize represents practices of large scale farms and neighboring ag enterprises; and in soybean these practices are represented by the FP N1 treatment.

Distinguished from A-sites, Global Maize C-sites are single-year field experiments with maize that are conducted simultaneously at several neighboring locations. These short-term experiments examine crop response to N, P and K using nutrient omission plots (**Table 2**). These C-sites used ample nutrient rates to avoid any deficiencies. Maize was preceded in the crop rotation by winter wheat.

All experiments were conducted on a calcareous common chernozem (**Table 3**). The soil had a clay loam texture, high pH, and low OM content. Average initial contents of nitrate-N (NO_3-N) ranged from medium to "increased" (0 to 20 cm soil layer). Soil extraction with 1% ammonium carbonate $[(NH_4)_2CO_3]$ found the site to have medium and "increased" levels of available P and K, respectively. For comparison, Olsen P and exchangeable K (1 N ammonium acetate [NH_4OAc] ex-

Abbreviations and Notes: N = nitrogen; P = phosphorus; K = potassium; Mo = molybdenum; $ZnSO_4$ = zinc sulfate; Zn = zinc; NH_4NO_3 = ammonium nitrate; KCl = potassium chloride; MAP = monoammonium phosphate; OM = organic matter; ppm = parts per million. IPNI Project: IPNI-2011-RUS-GM41.

Table 1. Fertilizer treatments applied to maize and soybean rotation "A-sites" in Tselina, Rostov.

Maize var. Furio (hybrid)	
Treatment	Description
FP N1	N_9P_{40} applied in spring before planting.
FP N2	$N_{30}P_{40}$ applied in spring before planting.
EI N1	$N_{17}P_{70}K_{40}$ split between a pre-plant ($N_{12}P_{50}K_{20}$) and planting application ($N_5P_{20}K_{20}$) placed 2 cm to the side of the seed.
EI N2	$N_{85}P_{70}K_{40}$ split between a pre-plant ($N_{50}P_{50}K_{20}$), at planting ($N_5P_{20}K_{20}$) placed 2 cm to the side of the seed, and N_{30} side-dressed at the V3 to V5 stage.
Soybean var. Donskaya 9	
FP N1	N_9P_{40} applied in spring before planting
FP N2	$N_{20}P_{40}$ applied in spring before planting
EI N1	$N_{10}P_{45}K_{30}$ applied in spring before planting
EI N2	$N_{30}P_{45}K_{30}$ applied in spring before planting

Sources for N and K were NH_4NO_3 and KCl, respectively. P and K rates are presented as P_2O_5 and K_2O. Rates shown are kg/ha.

tractable) tests found P to be within the "increased" interpretation class using the proposed ranges for Ukraine (Khristenko and Ivanova, 2012), while exchangeable K was high at all experimental sites.

Results

The highest average yield of maize of 6.95 t/ha was obtained through local EI management and its average improvement over FP was 8% (**Table 4**). Maize responded only slightly to added N in both the EI and FP management systems. The average yield increase due to N ranged from 4 to 6%. This low response may be explained by adequate NO_3-N levels in the soil.

The highest average yield of soybean of 1.96 t/ha was also obtained through EI management and the improvement over FP reached 25% (**Table 5**). The yield response to additional N over the low N treatment, for both the EI and FP management,

Table 2. Fertilizer treatments applied to maize "C-sites" in Tselina, Rostov.

Treatment	Description
Control	No fertilizer
FP	$N_{30}P_{40}$
NPK	$N_{100}P_{80}K_{60}$
PK[†]	$N_{18}P_{80}K_{60}$
NK	$N_{100}K_{60}$
NP	$N_{100}P_{80}$

[†]Not a strict PK treatment since MAP was used as the source of P. Sources for N and K were NH_4NO_3 and KCl, respectively. P and K rates are presented as P_2O_5 and K_2O. Fertilizers were applied in spring before planting maize var. Furio (hybrid). Rates shown are kg/ha.

Table 3. Initial soil characteristics at the experimental sites, Tselina, Rostov.

Site	Location	OM, %	pH	NH_4-N	NO_3-N	Avail. P[†]	Olsen P	Avail. K[†]	Exch. K[††]
				--- ppm ---
A	SVTU Tselinkiy	2.9	7.9	20	14	10	16	259	384
C	Ag. enterprises	3.2	7.7 to 7.8	14-19	12-16	10-11	16-18	254-276	354-375

[†]1%$(NH_4)_2CO_3$ extractable. [††]1N NH_4OAc extractable.
Weighted averages were calculated for the 0 to 20 cm soil layer based on soil tests for three depths (0 to 5, 5 to 10 and 10 to 20 cm). OM content was measured in 2011 at the C-site.

Table 4. Effect of nutrient management on maize grain yield, A-site, Tselina, Rostov.

Treatment	---------- Yield, t/ha ----------				Yield increase due to N, %
	2011	2012	2013	Average	
FP N1	7.78	6.70	4.03	6.17	-
FP N2	8.12	6.76	4.44	6.44	4
EI N1[†]	8.33	6.98	4.28	6.53	-
EI N2[†]	8.78	7.33	4.73	6.95	6
LSD$_{0.05}$	0.27	0.08	0.22		

[†]Seeds were treated with $ZnSO_4$.

Table 5. Effect of nutrient management on soybean seed yield, A-site, Tselina, Rostov.

Treatment	---------- Yield, t/ha ----------				Yield increase due to N, %
	2011	2012	2013	Average	
FP N1	1.81	1.22	1.68	1.57	-
FP N2	1.86	1.27	1.90	1.68	7
EI N1[†]	2.06	1.46	2.02	1.85	-
EI N2[†]	2.21	1.50	2.16	1.96	6
LSD$_{0.05}$	0.11	0.11	0.16		

[†]Seeds were inoculated and treated with Mo in 2011 and 2012 and treated with Mo in 2013.

Table 6. Effect of nutrient management on soybean seed quality (3-year average), A-site, Tselina, Rostov.

Treatment	Protein	Oil	Protein yield	Oil yield
	-------- % --------		-------- kg/ha --------	
FP N1	40.1	18.3	556	248
FP N2	42.4	17.8	629	260
EI N1[†]	43.4	19.2	706	309
EI N2[†]	45.6	19.2	789	328

[†]Seeds were inoculated and treated with Mo in 2011 and 2012 and treated with Mo in 2013.
Protein and oil content are expressed on a dry matter basis.

Table 7. Effect of nutrient management on maize grain yield, C-sites, Tselina, Rostov.

Treatment	---------------- Yield, t/ha ----------------			
	2011	2012	2013	Average
Control	7.45	6.61	4.78	6.28
FP	8.09	6.95	5.13	6.73
NPK[†]	8.99	7.50	6.10	7.53
PK[†‡]	8.29	6.89	5.56	6.91
NK[†]	7.93	7.17	5.82	6.97
NP[†]	8.43	7.38	5.94	7.25
LSD$_{0.05}$	0.27	0.09	0.21	

[†]Seeds were treated with $ZnSO_4$.
[‡]Not a strict PK treatment since MAP was used as the source of P.

ranged from 6 to 7% and were not significant during all seasons.

Improvements in seed protein were obtained with both EI and FP management treatments that provided extra N fertilizer (**Table 6**). Protein yields were improved as a result of both grain yield increases and protein content improvements. The highest average protein yield of 789 kg/ha was obtained with EI N2. Our three-year studies thus show that application of 30 kg N/ha may be recommended for soybean grown in this southern agro-environmental zone of Rostov to improve protein production.

The highest maize yield from the single-year C-sites was 7.53 t/ha (three-year average), which was produced with the ample NPK treatment (**Table 7**). Grain yield increases over the control and FP were 20 and 12%, respectively. These short-term field experiments suggest maize yield can be increased by up to 10% as a result of increasing N application from 18 to 100 kg N/ha. Maize also showed a consistent yield response to higher P rates—as much as 13% better during the most favorable, highest yielding season of 2011. The following two seasons were less favorable for maize and the P response was less pronounced at 5%. These findings fall in line with expectations for a medium-testing soil.

A significant yield K response in maize of 7% was obtained in the most favorable year of 2011. Maize response to K fertilizer was lower in 2012-2013 at 2 to 3%. These results suggest that a significant maize response to K fertilizer application may be expected when grain yield of about 9 t/ha is formed. It is assumed that K supplying capacity of a calcareous common chernozem having an "increased" level of available K doesn't match plant K requirements in high yielding environments.

Average values for agronomic efficiencies for P (AE_P) and K (AE_K) were 7.0 and 4.7 kg grain/kg P_2O_5 or K_2O, respectively. These values are quite high considering the ample nutrient rates applied. Under the current price scenario, it is estimated that P and K fertilizer use in maize would be profitable with AE_P and AE_K values above 6.2 and 2.7 kg grain/kg P_2O_5 or K_2O, respectively. We took into consideration the average grain prices at farm gate in the fourth quarter of 2013 and the average prices for MAP and standard KCl in the first quarter of 2014 excluding the costs of fertilizer delivery to the farm, fertilizer application, and additional harvesting and drying for the added grain yield.

Global maize A-site showing maize plots comparing FP (top left) and EI (top right) on July 2013; and soybean plots in August 2011 (left to right) Drs. Nosov, Kuprov and Biryukova.

Summary

Optimization of plant nutrition with macro- and micronutrients is very important in improving productivity of maize and soybean grown in Southern Russia. This three-year field experiment showed that a local EI management system contributed to 8% and 25% more grain production for maize and soybean, respectively, compared to FP. In soybean, an EI system that included 30 kg N/ha also improved the protein content of harvested seeds. Profit analysis from nutrient omission C-sites revealed that the selected "ample" P and K rates were profitable under moderate and above-medium levels of available P and K, respectively. BC

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Crop Straw Can Optimize Potassium Fertilization Strategies in Rice Cropping Systems

By Ji-fu Li, Jian-wei Lu, Tao Ren, Ri-huan Cong, Xiao-kun Li, and Li Zhou

Generalized fertilizer recommendations for K in China exist partly because of a lack of local evidence disproving their use, and partly to address limited fertilizer K resources. This research demonstrates how making good use of the nutrient value of crop straw can help optimize fertilizer K application and reduce the reliance on strategies that promote generalized fertilizer recommendation systems across large areas.

Paddy-upland rotations, located mainly in the Yangtze River basin, arguably form the most important cropping systems in China. However, rice and subsequent crops like wheat, rice, or oilseed rape remove large amounts of K annually, from 210 to 360 kg K_2O/ha/yr, in part because of the removal of crop straw from fields. As a result, soil K deficiency has become a key limiting factor for sustained high yields due to relatively low rates of K input in the region. However, besides K fertilizer, it is always important to consider all potential K resources available to farmers within a region.

The K in crop straw left in the field is a readily available source that is released quickly for plant use, especially under flooded conditions. Changes towards large-scale mechanization in Chinese agricultural production are providing favorable conditions to expand the practice of returning crop straw to fields. This article examines a 2011-2012 study (IPNI China, 2012) that measured the impact of crop straw on the K nutrition of rice, its yield, and optimal fertilizer K application rates.

According to China's second national soil survey, trial sites with available K content (1 N NH_4OAc extractable K) of >150 mg/kg (Zhongxiang and Yicheng sites) were classified as high K soils; those with available K content between 100 and 150 mg/kg (Tuanfeng, Xiantao, Honghu, and Zhijiang sites) were classified as medium K soils; and those with available K content <100 mg/kg (Macheng, Guangshui, Ezhou, and Qichun sites) were classified as low K soils. Earlier on-site investigation revealed that crop straws are always removed from the farmland for rice transplanting. Field experiments were carried out in a randomized block design with six treatments including: 1) zero-K check, 2) the generalized K recommendation of 75 kg K_2O/ha, 3) 4.5 t/ha wheat straw/winter rape straw (with ~2.1% K content), and 4) straw combined with two lower rates of K fertilizer (i.e., 25 and 50 kg K_2O/ha). The crop straw was mechanically chopped to a length of 10 cm and then incorporated into the soil with the fertilizer.

Linear and plateau K fertilization models (Cerrato and Blackmer, 1990) were used to determine the optimum levels of K fertilization:

$$y = a + bx \ (x \leq C)$$
$$y = P \ (x > C)$$

where, y is the grain yield (kg/ha), x is fertilizer K rate (kg/ha), a is the intercept, b is the regression coefficient, C represents the intersection of the straight line and the plateau, and P is the plateau yield (kg/ha). Px and Py are the prices of K_2O (4.5 Yuan/kg) and of rice (2.5 Yuan/kg) during 2011-2012 in

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; NH_4Oac = ammonium acetate.

Comparisons at a low soil K site showing the general K fertilizer recommendation (top left), the zero K check (top right), K plus Straw (bottom left), and K minus Straw (bottom right).

China. When b > Px/Py, C is the recommended amount of K; when b < Px/Py, the recommended amount of K is 0.

Results

Potassium fertilization and K input from crop straw residue both contributed to better rice yields, but their impact depended on soil K status (**Table 1**). Yield responses to the generalized K or straw treatments alone were similar in size, but not significantly greater than the check across soil fertility levels. Only the fertilizer and straw K treatment generated better yields, which were significantly higher than the check treatment in low and medium K soils.

Table 1. Effect of straw incorporation and K fertilization on rice yield and K uptake, Yangtze River Basin.

Soil K levels	Treatment	Yield, kg/ha	Yield increase, kg/ha	Yield increase, %	K uptake, kg/ha	K uptake increase, kg/ha	K uptake increase, %
High K	Check	8,372 a	-	-	253 b	-	-
	K[†]	8,635 a	263	3.1	285 a	32	12.6
	Straw[‡]	8,852 a	480	5.7	278 a	25	9.9
	Straw + K	9,005 a	633	7.6	293 a	40	15.8
Medium K	Check	8,710 b	-	-	265 b	-	-
	K	9,460 ab	750	8.6	305 a	40	15.1
	Straw	9,023 ab	313	3.6	279 b	14	5.3
	Straw + K	9,808 a	1,098	12.6	322 a	57	21.5
Low K	Check	7,767 b	-	-	170 c	-	-
	K	8,376 ab	609	7.8	194 b	24	14.1
	Straw	8,019 ab	252	3.2	185 b	15	8.8
	Straw + K	8,503 a	736	9.5	212 a	42	24.7

[†]General recommendation of 75 kg K_2O/ha. All treatments received 165 kg N/ha and 45 kg P_2O_5/ha.
[‡]Straw applied at 4.5 t/ha. Means in the same column followed by the same letter are not significantly different at p = 0.05.
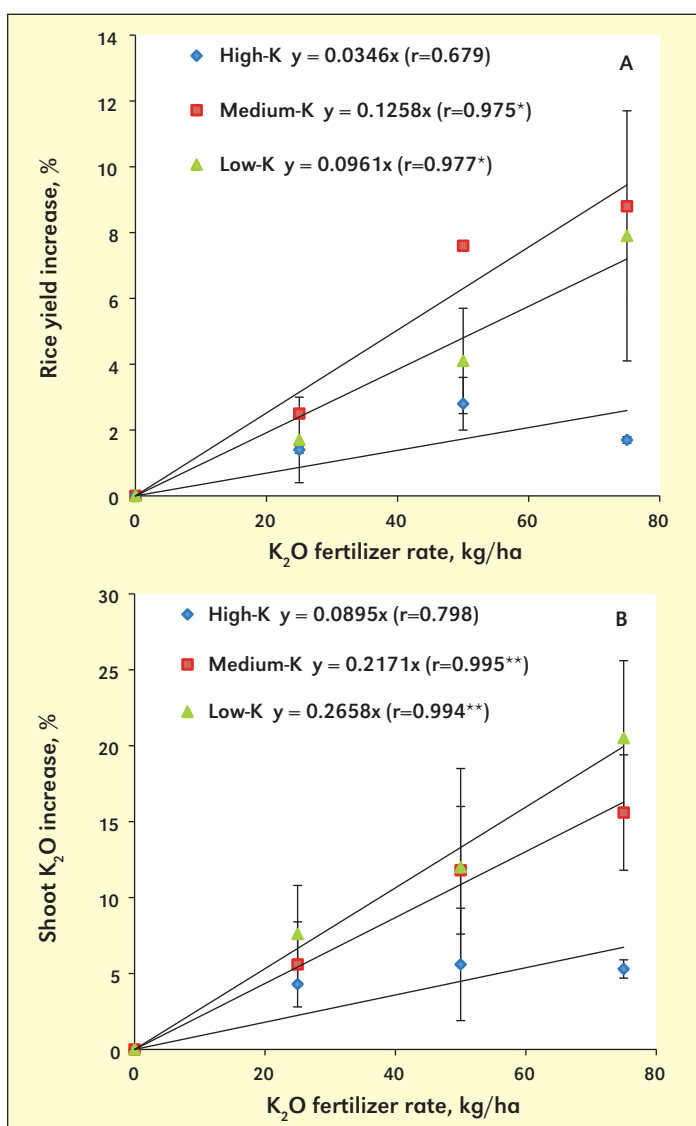
Figure 1. Relationships between yield increase (A), K uptake (B) and K fertilizer rate with crop straw incorporation, Yangtze River Basin. * and ** denote significance at p = 0.05 and p = 0.01, respectively.

As with the yield responses, K fertilization also led to an increase in K uptake in rice biomass in high, medium and low K soils (**Table 1**). Straw input most affected crop K uptake in low and high K soils and was less effective in medium K soils. The fertilizer and straw K treatment produced the highest K uptake values across all soils.

Impact of Straw on Potassium Uptake and Yield

With straw incorporation, the yield increases in different soils varied with K fertilizer rates (**Figure 1a**). Linear equations were significant for the plots of yield increase and K application rate for both medium and low K soils, but the correlation was non-linear in high K soils. In medium K soils, while the K fertilizer rate increased by 30% (i.e., 50 to 75 kg/ha) the yield only increased from 7.6 to 8.8%. This indicates that surplus K^+ ions were absorbed by the rice crop grown on medium K soils. For low K soils, the present generalized recommendation for K fertilizer was found to be inadequate.

Similarly, **Figure 1b** shows the linear equations fit to plots of the increase in shoot K versus K fertilizer application rate across soil fertility levels. Although the linear correlation was not significant for high K soils, K accumulation tended to increase linearly with K fertilizer application rate in medium and low K soils. There are risks of luxury K absorption, such as the change in the K:Mg ratio if the straw is used for fodder (Römheld and Kirkby, 2010), due to excess K application in medium K soils, while in low K soils the need for additional K input via fertilizer to meet rice production goals is apparent.

Optimal Fertilizer Potassium Rates in Rice with Straw Incorporation

Two 15-year field experiments carried out in the Sichuan Basin indicated that soil K reserves could be used to predict the application rates of K fertilizer (IPNI China, 2012). The yield response data in **Figure 1** suggests that the current K fertilizer recommendation of 75 kg K_2O/ha is excessive for high and medium K soils supplied with 4.5 t/ha of incorporated wheat or oilseed rape straw. Yet, on low K soils, the general fertilizer recommendation plus straw is still not adequate to meet the demands of high yielding rice crops. The optimal amount of fertilizer K to be combined with straw is presented according to the linear and plateau models (**Table 2**). For example, in high K sites at Zhongxiang and Yicheng, the corresponding optimal rates of K fertilizer were 36 kg/ha and 40 kg/ha, or about half of the generalized recommendation. For medium K soils, the optimal K fertilizer rate averaged 60 kg/ha or 80% of the generalized recommendation.

Entire Yangtze River Basin area within China.

Summary

The K nutritional needs of paddy rice can be effectively met through the combination of K fertilizer and recycled crop straw. Although K fertilization had better effects on yield and K uptake than straw return alone in medium and low K soils, the opposite was true in high K soils. Using a linear and plateau fertilization model, the optimal K fertilizer rates for high and medium K soils averaged 38 and 60 kg/ha, respectively. But for low K soils, the current generalized recommendation of 75 kg K_2O/ha is insufficient and needs to be increased to ensure both high rice yields and soil K fertility. ⬛

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Table 2. Optimal fertilizer K rates for rice with straw incorporation, Yangtze River Basin.

Soil K levels	Sites	Min. yield, kg/ha	Max. yield, kg/ha	Optimum K_2O rate, kg/ha	R^2
High K	Zhongxiang	8,281	8,447	36.1	0.976*
	Yicheng	9,423	9,658	40.4	0.739
Medium K	Tuanfeng	9,798	10,375	62.7	0.961*
	Xiantao	9,682	10,604	58.6	0.955*
	Honghu	8,333	9,852	56.1	0.963*
	Zhijiang	8,101	8,400	62.6	0.961*

Based on linear and plateau K fertilization models (Cerrato and Blackmer, 1990).

Development of an Australian Soil Test Calibration Database

By Simon Speirs, Mark Conyers, Doug Reuter, Ken Peverill, Chris Dyson, Graeme Watmuff, and Rob Norton

Almost 6,000 fertilizer response experiments were collated and made available through a web-based tool. Advisers can use this tool to estimate soil test critical ranges by crop, region, soil type and nutrient.

Soil testing remains a most valuable tool for assessing the fertilizer requirement of crops. The relationship between soil tests (generally taken from surface soil) and relative yield (RY) response to fertilizer is subject to the influence of environment (e.g., water, temperature) and management (e.g., cultivation, sowing date).

The traditional way to determine soil test critical values is from experiment-specific critical values that are season and soil type-specific and lack statistical power to make reliable estimates. In many cases, the experiments used to define critical values are only ones where significant responses are seen; so non-responsive sites are not represented. As such, the degree of precision is often low when the soil test calibration is based on a wide range of independent experiments conducted on many soil types, over many years, by many different scientists.

To aggregate existing soil test and crop response data, an online MySQL database of historic fertilizer response trials has been developed for cereals, pulses and oilseed crops in Australia's diverse cropping regions. The data includes 5,420 single and multiple nutrient field experiments from five decades of research. It consists of data from all available N (1,709 experiments), P (2,281 experiments), K (356 experiments), and S (270 experiments) trials. Minimum data trial requirements were applied, which stipulated that the soil type was recorded, a recognized soil test had been undertaken, and that an estimate of crop yield with no fertilizer (Y_0) and the maximum yield (Y_{max}) could be obtained from the rate range used. Crop grain yield responses were fitted with either Mitscherlisch, quadratic or logistic functions to estimate Y_0 and Y_{max}, and the percentage of RY as $100*Y_0/Y_{max}$.

Using the trial data, soil test critical values can be derived online through the Better Fertilizer Decisions for Cropping Interrogator Tool, which was specially developed for manipulating, sorting and searching the database. A trained and registered user is able to filter the data by attributes that include crop type, soil type, soil test, yield, and growing season rainfall. Fertilizer response criteria are obtained by fitting an inverted plot of the natural logarithm for the soil test and the arcsin of the square root of RY. From these curves, critical soil test values and confidence limits for 80%, 90% and 95%

Figure 1. An example of the online Interrogator interface at the first (a) and second stages (b) of database interrogation.

of RY can be derived.

Figure 1 shows two screen shots from the web-based interface. The first screen (**Figure 1a**) allows the user to select trials based on the nutrient (N, P, K, or S), the crop, the soil types of interest, a state or a selected region, a time scale, and from irrigated or dryland farming systems. The second screen (**Figure 1b**) allows a soil test and sampling depth to be selected from the database, as well as some additional filters such as soil pH, soil texture, drought, etc. The fertilizer response

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; BFDC = Better Fertilizer Decisions for Cropping.

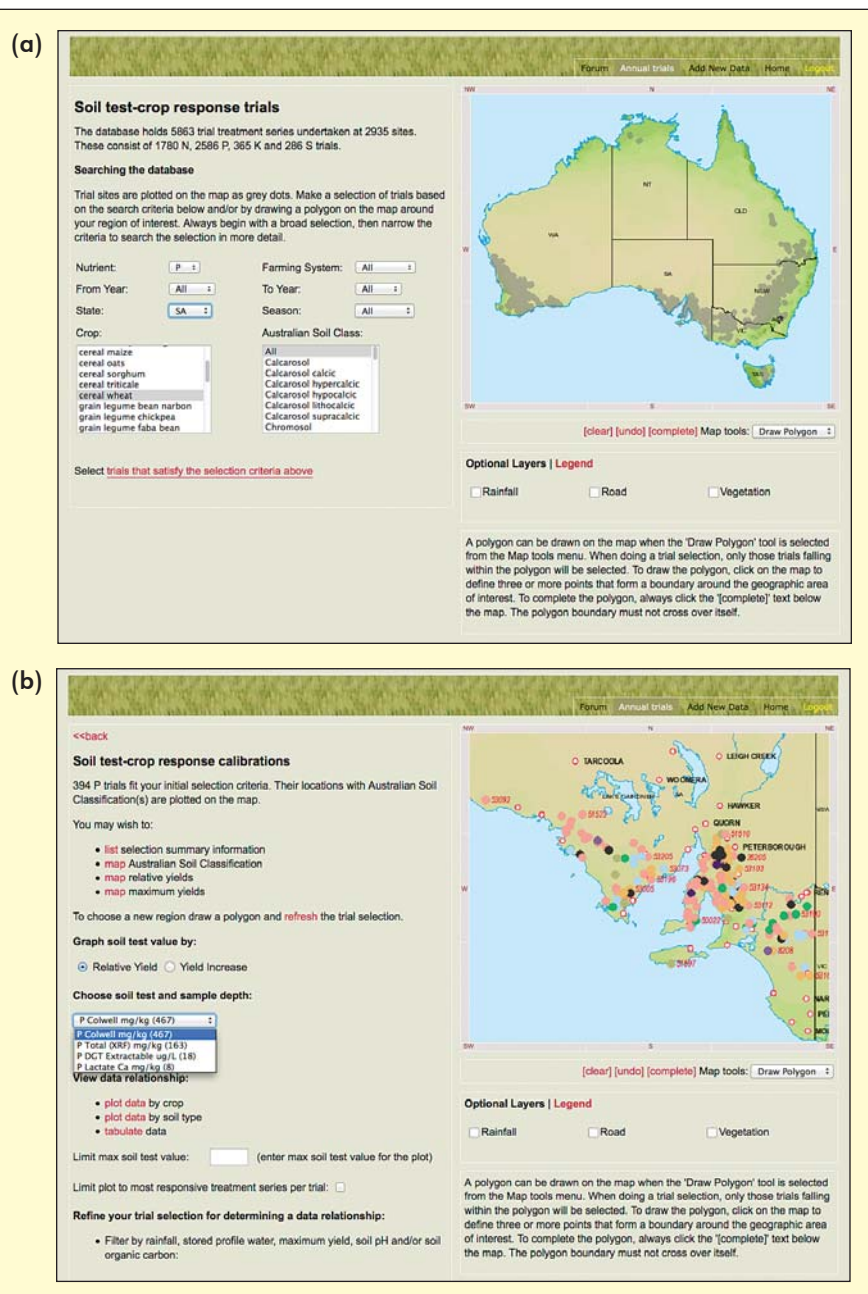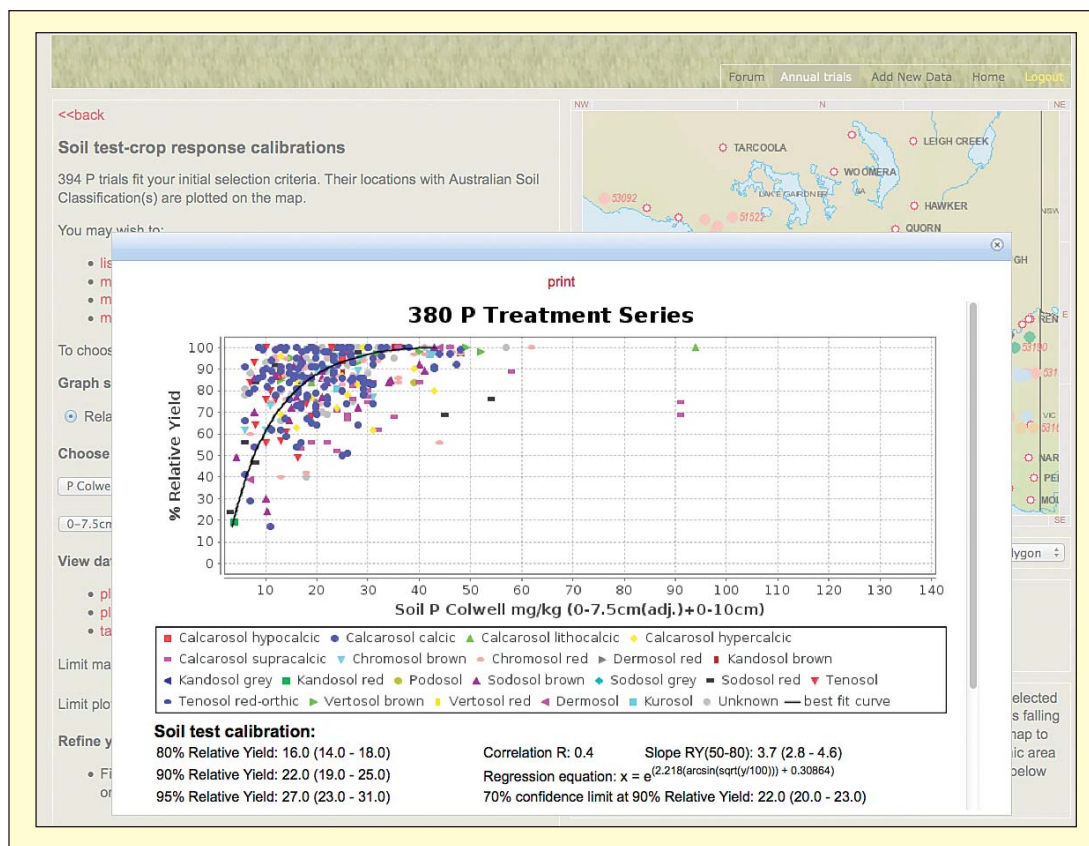**Figure 2.** An example final report on the derived critical soil test value.

curve against soil test value is presented to the user on the screen, with these values indicated as well as the correlation values for the relationship (**Figure 2**).

The Interrogator enables users from the grains and fertilizer industries to better estimate soil test critical values for their particular situations, and to improve fertilizer management. The database underpins the Australian fertilizer industry's Fertcare program for advisers making recommendations to grain growers. It also assists and directs future research to address any identified knowledge gaps. The Interrogator was commissioned in March 2012 and can be found at www.bfdc.com.au.

As well as developing the database and training users in extracting and interpreting the information, the core scientific group published a series of papers to document the processes undertaken, and the outcomes in terms of the reliability and critical values of particular soil tests. A special edition of Crop and Pasture Science (CSIRO, 2013) was devoted to soil test interpretation as well as procedures and lessons learnt from the project.

The process of collating and entering data was very time consuming and relied on a lot of unpublished data provided personally by soil fertility researchers as well as through published information. A large amount of institutional input was required as well as good faith and trust among organizations and researchers on how the data were to be handled.

A second major issue was a lack of standardized metadata for sites within the database, which makes it generally impossible to isolate the effects on critical values of the specific management or environmental factors that are therefore best determined by specific studies. The database provides guidance, but in general—even with the large set collated here—specific issues such as the impact of stubble retention or the effect of zero-tillage can not be addressed.

Finally, the database is dominated (60%) by responses of wheat to N and P, meaning that relatively few studies are available for responses by pulses (other than narrow leaf lupins) or oilseeds (other than canola), especially for K and S. Moreover, limited data are available for current cropping systems and varieties. However, the identification of these gaps can now be used to focus future research on the crops, nutrients, soils, regions, and management practices where data are lacking.

The BFDC National Database and BFDC Interrogator is an approach that is worth examining for those nations that have a legacy of fertilizer response experiments, but have not used "information technology" tools to assemble their data. In those nations that are still conducting many fertilizer response experiments, the approach outlined for standardizing protocols and developing a database and an interrogator should be of great value for capturing long-term benefits from present investments. BC

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Proper Timing and Placement of Boron and Lime Impacts Legumes on Acid Upland Soils

By Surendra Singh and Ravindra Naryan Singh

Soil acidity creates many serious crop production problems, and on the acid upland soils of Jharkhand State in India low plant-available B is a prominent concern. Use of in-furrow B and lime just prior to planting proved effective at producing better soybean, groundnut, lentil, pigeon pea, and gram crops—all of which are critical food and income sources for this region.
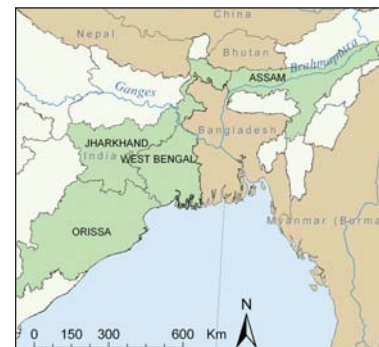
The upland soils of Jharkhand occupy an area of 300,000 ha and represent an important rainfed-production zone suited to grain legume cultivation. However, the region generally has low crop productivity, which is blamed on common regional issues such as soils with coarse texture, low water and nutrient retention capacity, low base saturation, and soil acidity. Low fertilizer use (e.g., 30 kg of total $N+P_2O_5+K_2O$/ha application) is also commonplace and deficiencies of N, P, K, S, and B are widespread.

Boron deficiency extensively affects crops on acidic soils in the states of Assam, Orissa, West Bengal, and Jharkhand (Sarkar et al., 2010). Legumes and pulses are highly sensitive to B deficiency, which partly explains their low productivity in the region. The correction of (a) B deficiency through fertilization and (b) soil acidity through liming have the potential to improve crop productivity and quality, thus, providing better livelihood opportunities for farmers in the region. Mathur et al. (1991) showed the benefits of in-furrow application of small rates of lime in grain legumes as compared to simple surface broadcasting. This article presents an evaluation of the advantages of co-applying B plus lime, along with other recommended nutrients, on major legume and pulse crops grown in the region.

Field experiments were conducted from 1995 to 2005 during *Kharif* (monsoon) and *Rabi* (winter) seasons at an upland location in east Singhbhum district in Jharkhand. Soils were coarse-textured with pH values (soil:water w/v ratio of 1:2.5) between 5.1 to 5.5, organic carbon (OC) of 0.2 to 0.4%, potentially mineralizable N (alkaline permanganate method) between 140 to 231 kg/ha, available P (Bray 1-P method) between 7.9 to 9.8 kg/ha, available K (1 N ammonium acetate) between 160 to 210 kg/ha, and available B (hot water extractable) between 0.26 to 0.47 mg/kg.

To control soil acidity, just prior to each crop seeding, 300 to 400 kg/ha of powdered lime (1/10th of the measured lime requirement) was applied within furrows opened at the recommended row spacing of 15 to 20 cm. The lime was mixed in the soil, and then B was applied and mixed in soil. NPK fertilizers were applied in the same furrows at recommended rates (**Table 1**) and mixed again with soil. Seeds were sown in the opened furrows and finally covered with soil. Boron was applied using borax (10.5% B) at rates varying from 0.5 to 4.0 kg B/ha, while fertilizer N, P and K sources used were urea, TSP and KCl.

Berger and Truog (1939) determined a critical limit of 0.5 mg/kg of hot water-extractable B to delineate B deficiency or sufficiency in soils. **Table 2** shows the extent of B deficiency in different districts of Jharkhand, which varies from 4% in

Table 1. Recommended N, P, K and B application rates for the major legume and pulse crops grown in east Singhbhum, Jharkhand, India.

Crops	N	P_2O_5	K_2O	B
	--------- kg/ha ---------			
Legumes				
Soybean	20	60	20	0.5-2.0
Groundnut	25	50	20	1.0-2.0
Pulses				
Lentil	20	40	20	1.0-4.0
Pigeon pea	20	20	16	1.0-2.0
Gram	20	40	20	0.5-2.0

Table 2. Distribution of B-deficient and acid (pH<5.5) soils in different districts of Jharkhand, India.

District name	Approximate area, '000 ha	Area with severe to moderate acidity, %	Area with low available B, %	Range of available B, mg/kg
West Singhbhum	718	74	38	0.02-7.2
East Singhbhum	354	72	77	0.02-0.9
Saraikela	272	67	55	0.03-3.0
Ranchi	770	73	43	0.02-3.5
Simdega	377	73	46	0.01-2.3
Gumla	532	69	49	0.02-3.3
Lohardaga	149	72	71	0.04-1.1
Latehar	14	50	35	0.02-1.6
Palamau	509	4	67	0.02-4.2
Chatra	382	19	23	0.07-4.5
Hazaribagh	502	53	39	0.03-7.9
Koderma	240	26	24	0.02-5.8
Giridih	494	56	47	0.02-5.2
Deoghar	248	38	45	0.03-1.9
Dumka	441	48	27	0.11-7.2
Godda	211	28	25	0.05-9.0
Sahebganj	159	22	38	0.07-3.8
Pakur	180	41	27	0.10-7.2
Jamtara	180	64	23	0.02-6.1
Dhanbad	209	60	04	0.22-5.9
Bokaro	286	70	22	0.09-5.0
Garhwa	404	5	71	0.01-3.0
Overall	7,629	52	41	0.01-9.0

Source: Sarkar et al. (2010).

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; B = boron; KCl = potassium chloride; TSP = triple superphosphate.

Boron deficiency in soybean field (center strip) with unaffected strip seen on the right.

Dhanbad to 77% in east Singhbhum. The wide variation in B deficiency across districts is probably related to variable soil OC contents and the differences in losses of borate ions due to leaching from these coarse-textured soils.

A soil application of 0.5 to 2.0 kg B/ha as borax to soybean, groundnut, lentil, pigeon pea, and gram gave yield responses of 115, 61, 66, 179, and 73 kg grain/kg of applied B, respectively (**Table 3**). Groundnut and pigeon pea yields increased by 34 and 61%, respectively, with B and lime application. Similarly, the application of lime and 2 kg B/ha increased the protein content in groundnut and pigeon pea seeds by 11 and 18%, respectively, while the protein content in gram increased appreciably with the application of 1 kg B/ha and lime (**Table 4**). As observed with yield, B application improved the profitability for each crop in the following order: pigeon pea > groundnut > lentil > soybean > gram (**Table 5**).

Summary

Use of B and lime in the acidic upland soils of Jharkhand produced higher legume and pulse crop yields with higher protein content. There is a need to popularize the practice of targeted in-furrow placement of lime and fertilizers with resource poor farmers producing these food and cash crops that are of critical

Table 3. Effect of lime and B application on yields of major legume and pulse crops grown in the acidic upland soils of east Singhbhum, Jharkhand, India. Data shown is the average of three years for each crop.

	Optimum B[‡] rate, kg/ha	- - - - - - - Yield, kg/ha - - - - - - - NPK + Lime	NPKB + Lime	Response, kg grain/kg B	References
		Legume crops (1995-2003)			
Soybean	2.0	1,390	1,620	115 (16.5)*	Singh et al. (2006)
Groundnut	2.0	943	1,263	160 (33.9)	Singh et al. (2004a)
		Pulse crops (1995-2005)			
Lentil	2.0	865	1,070	103 (23.7)	Kushwaha et al. (2009)
Pigeon pea	2.0	1,041	1,673	316 (60.7)	Singh et al. (2004a)
Gram	1.0	876	966	90 (10.2)	Singh et al. (2004b)

LSD (p=0.05) for soybean = 80; groundnut = 61; lentil=66; pigeon pea =179 and gram =73. ‡Applied as Borax. *Percent (%) response to B application (i.e., % increase in grain yield with B application compared to no B application).

Table 4. Effect of lime and B application on protein content in grains of major legume (1995-2003) and pulse (1995-2005) crops grown in the acidic upland soils of east Singhbhum, Jharkhand, India.

	Optimum B[‡] rate, kg/ha	- - - - Protein content, % - - - - NPK + Lime	NPKB + Lime	B response, %	References
		Legume crops			
Soybean	2.0	35.8	36.7	2.5	Singh et al. (2006)
Groundnut	2.0	24.4	27.2	11.4	Singh et al. (2004a)
		Pulse crops			
Lentil	2.0	17.5	19.1	9.1	Kushwaha et al. (2009)
Pigeon pea	2.0	18.1	21.3	17.6	Singh et al. (2004a)
Gram	1.0	17.9	19.7	10.0	Singh et al. (2004b)

LSD (p=0.05) for soybean = 0.2; groundnut = 1.2; lentil = 0.6; pigeon pea = 0.7 and gram = 0.5. ‡Applied as Borax. Data shown is the average of three years for each crop.

Table 5. Profits obtained with B application on major legume (1995 -2003) and pulse (1995-2005) crops grown in the acidic upland soils of east Singhbhum, Jharkhand, India.

	Optimum B[†] rate, kg/ha	B response, kg grain/kg B	Increase in income/kg of applied B, ₹
Legume crops			
Soybean	2.0	115	2,944
Groundnut	2.0	160	6,400
Pulse crops			
Lentil	2.0	103	2,987
Pigeon pea	2.0	316	13,588
Gram	1.0	90	2,700

[†]Applied as Borax. Prices/costs of crops and fertilizers used per kg were: ₹25.60 for soybean, ₹40 for groundnut, ₹29 for lentil, ₹43 for pigeon pea and ₹30 for gram; ₹78 for borax. ₹59 (Indian Rupee) = US$1. Data shown is the average of three years for each crop.

importance to this region. BC

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Symposium Themes include:
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- Advancing global food security with analytical tools
- Making recommendations using nutrient ratios
- Environmental stewardship and sustainability
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For more details on key information, please visit the Symposium's website www.isspa2015.com BC

Adapting Management of Nitrogen Sources and Weeds in Flax Systems of Central Iowa

By Stefan R. Gailans and Mary H. Wiedenhoeft

Expansion of flax into the Midwestern U.S. has created a gap in regionalized knowledge on N source and weed management for this crop. Recent experiments in central Iowa found good responses across selected N sources, but results varied between the two very distinct growing seasons. Composted manure had the largest impact on reducing harvest index relative to other N sources in the initial year, but not the following, more challenging growing season. Weed competition had the most pronounced effect on flax yields compared to the effects of N source and rate. Weed biomass also increased with N rate, emphasizing the need for effective weed management in flax production systems.

Production of flax (*Linum usitatissimum* L.) has increased in North America over the past decade, due to markets driven by the recognition of the potential health benefits of including flax seed in the human diet. Knowledge of appropriate conventional and organic production practices for production in the Midwest, U.S. is lacking, as much of the research in North America originates in North Dakota, Manitoba, Saskatchewan and Alberta on the Northern Great Plains. Midwestern research is necessary to develop N recommendations for flax growers in this region. Additionally, adequate management of weeds is of particular concern for growers of flax due to its lack of competitiveness (Franzen, 2004).

Researchers evaluated the response of flax to three N sources applied at three N rates in the presence and absence of weed competition. This study occurred in 2007 and 2008 at the Iowa State University Agronomy and Agricultural Engineering Farm located near Ames in central Iowa. In both years, the experiment took place in fields planted to soybeans the previous year. Composted swine manure, fresh liquid manure, and urea were surface applied by hand to plots at 0, 30, 60, and 90 lb N/A and immediately incorporated into the soil. Nutrient analyses and applied rates of compost and manure are provided in **Table 1**. Each N source x rate combination

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Table 1. Nutrient analyses of composted swine manure and liquid swine manure and the amount applied to meet target N rates in 2007 and 2008. Ames, Iowa.

	Nutrient analysis			Target N rate, lb N/A		
	Total N	Total C	Moisture	30	60	90
Compost	- - - - - - - - % - - - - - - - -			ton/A		
2007	2	19	31	7	14	21
2008	2	34	77	12	25	37
Manure	lb/1,000 gal		%	gal/A		
2007	28	-	98	1,053	2,000	3,053
2008	26	-	96	1,158	2,316	3,474

Amount of compost and manure applied was based on the availability of 10% of the total N in the compost and 98% of the total N in the manure.

Abbreviations and notes: N = nitrogen.

was replicated four times. Flax was drilled into plots at 8-inch row spacings at 50 lb/A accompanied by red clover (*Trifolium pratense* L.) broadcasted at 15 lb/A. Flax was underseeded with red clover to mimic a common management strategy used for production of small grains. Plots were split into randomized subplots that either contained uncontrolled weeds ('weedy') or were weed-free. Throughout the growing season, weeds were removed by hand as needed from weed-free subplots. At flax seed maturity in late July, aboveground shoot material of flax, red clover, and weeds was hand-harvested at the soil surface from four randomly located 1 ft² areas in each subplot. The linolenic acid (omega-3 fatty acid) concentration of seed oil was assessed upon harvest.

Impact of Weed Competition and N on Flax

In both 2007 and 2008, flax seed yield was significantly reduced by weed competition regardless of N source or rate applied. In 2007, mean seed yield was 709 and 995 lb/A under weedy and weed-free conditions, respectively. In 2008, mean seed yields under weedy conditions were 197 lb/A compared to 385 lb/A under weed-free conditions. Nitrogen source was not a factor in either year. Under weed-free conditions, seed yield responded to N rate in 2007 and 2008 (**Figure 1**). Regardless of N source, seed yield response to each incremental increase in N rate under weed-free conditions was linear (p = 0.05) with greatest yields occurring at the 90 lb N/A rate. Under weedy conditions, maximal seed yields were observed at the 60 lb N/A rate in 2007 and no response to N rate was
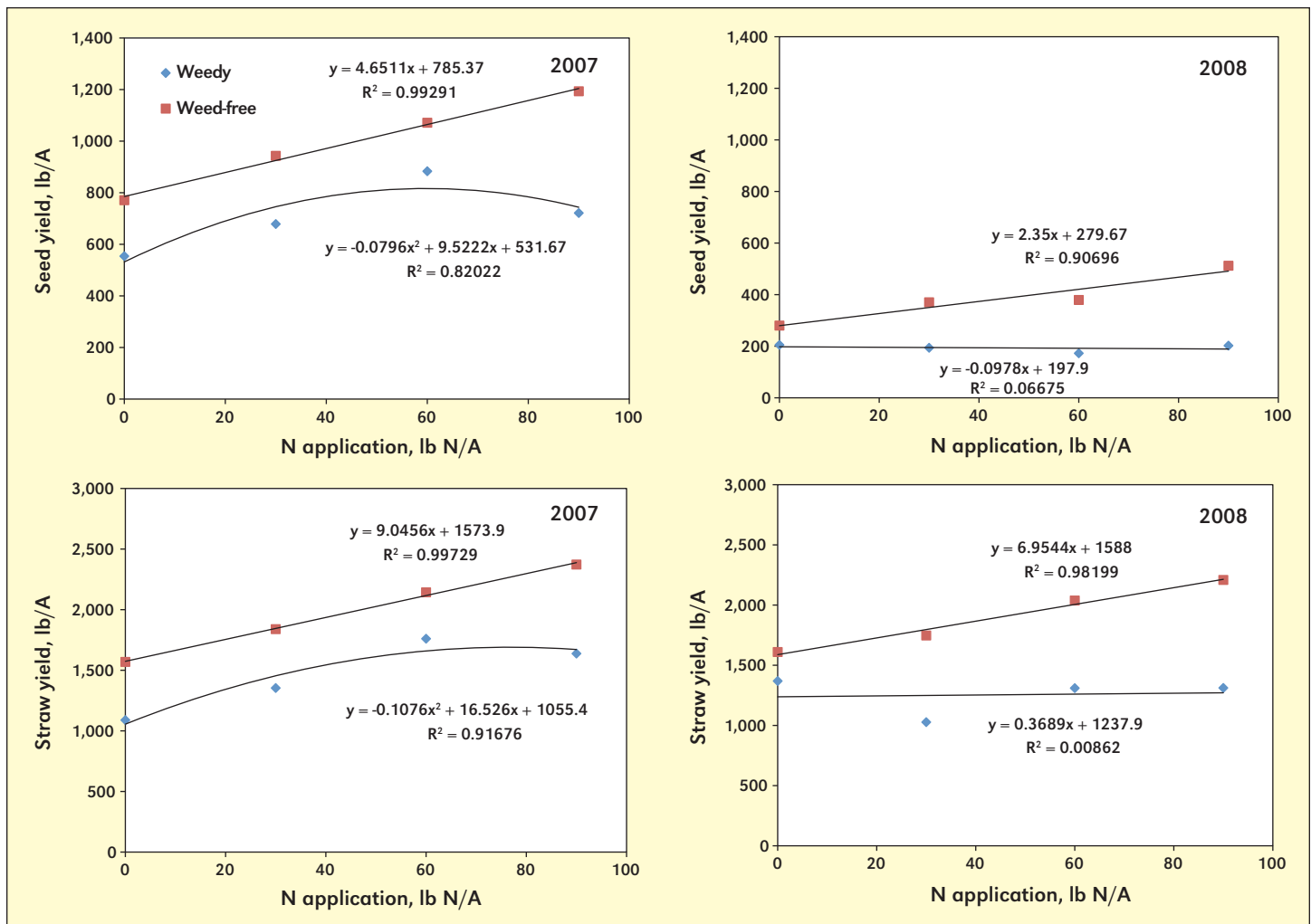
Figure 1. Flax seed yield (top) and straw yield (bottom) as affected by N rate under weedy and weed-free conditions in 2007 and 2008 in Ames, IA.

detected in 2008.

In 2007, linolenic acid content of seed oil was affected by N source and rate, but not weed competition (**Table 2**).

Compost resulted in the lowest linolenic acid content and N rate decreased linolenic acid content in a linear fashion (p = 0.0001). In 2008, linolenic acid content was affected by the three-way interaction of N source x N rate x weed competition (**Table 2**). Under weedy conditions, increasing N as compost (p = 0.0001) and urea (p = 0.0023) resulted in a negative linear response. Under weed-free conditions, only increasing N as compost resulted in a negative linear response (p = 0.0429).

As with seed yield, flax straw yield was significantly reduced by weed competition across N sources and rates in both years. In 2007, mean straw yields under weedy conditions were 1,460 lb/A compared to 1,981 lb/A under weed-free conditions. In 2008, mean straw yields under weedy conditions were 1,255 lb/A compared to 1,901 lb/A under weed-free conditions. Regardless of weed competition and across N rate, straw yield was consistently greater with compost compared to other N sources in 2007. No differences among N sources was observed in 2008. In 2007,

Table 2. Linolenic acid concentration of flax seed oil as affected by weeds, N source, and N rate in 2007 and 2008. Ames Iowa.

		--------- 2007 ---------				--------- 2008 ---------			
		N rate, lb N/A				N rate, lb N/A			
		0	30	60	90	0	30	60	90
Weeds	N source	------------------------------- % -------------------------------							
Weedy	Compost	50.7	49.9	47.3	45.1	51.4	52.0	51.5	44.8
Weedy	Manure	50.7	51.2	50.7	49.7	51.4	51.0	49.0	49.0
Weedy	Urea	50.7	49.6	49.4	47.6	51.4	52.0	47.1	44.3
Weed-free	Compost	50.9	50.4	49.6	49.2	53.0	51.7	52.6	51.9
Weed-free	Manure	50.9	50.9	51.0	50.6	53.0	53.0	52.3	51.7
Weed-free	Urea	50.9	50.4	50.0	49.6	53.0	53.1	51.8	51.7
Source of variation	------------------------- p value -------------------------								
Weeds (W)	0.1906				0.0034				
N source (S)	0.0001				0.2301				
N rate (R)	0.0001				0.0001				
W x S	0.0811				0.0800				
W x R	0.1008				0.0011				
S x R	0.1935				0.0416				
W x S x R	0.7256				0.0143				

straw yield response to N rate was linear (p = 0.001) under weed-free conditions and quadratic (p = 0.0001) under weedy conditions (**Figure 1**). In 2008, straw yield response to N rate was linear (p = 0.001) under weed-free conditions while no response to N rate was observed under weedy conditions.

In 2007 only, harvest index (the ratio of seed yield to the sum of seed and straw yield) was least when compost was applied (data not shown). While seed yield responded to each of the N sources equally, compost tended to have a disproportionate effect on straw yields. Despite the increase in straw yields with compost application, lodging of flax plants was not observed in these plots.

The late planting date (May 1st), above-normal precipitation, and very wet field conditions in 2008 relative to 2007 likely contributed to the reduction in flax seed yield in 2008. Significant seed yield reductions have been attributed to delaying planting at sites in Ontario (Sheppard and Bates, 1988), North Dakota (Thompson et al., 1988), and southern Saskatchewan (Lafond et al., 2008). With later plantings, vegetative growth of flax can be maintained due to an increased vegetative growth rate, but to the detriment of flower development period and seed yield (Dybing and Grady, 1994). Dybing (1964) attributed the negative effect of N on linolenic acid to the favoring of vegetative growth, which was also observed in the present study. We observed straw yield to increase with N in both years and at the same time reported a decrease in linolenic acid concentration.

Impact of N Source and N rate on Weeds

Common lambsquarters (*Chenopodium album* L.), common waterhemp (*Amaranthus rudis* Sauer), Pennsylvania smartweed (*Polygonum pensylvanicum* L.), and giant foxtail (*Setaria faberi* Herrm.) were the most prevalent weed species contributing to weed biomass in both years in the subplots that contained ambient weeds. Weed biomass increased with N applied as compost in 2007 and applied as any of the N sources in 2008 (**Table 3**). Previous research has found composted swine manure to increase biomass of common waterhemp in corn and soybean production systems in Iowa (Liebman et al., 2004; Menalled et al., 2004). Furthermore, increasing applied N was found to preferentially favor wild buckwheat (*Polygonum volvulus* L.) growth and subsequent flax yield reduction in a direct competition study (Gruenhagen and Nalewaja, 1969). This points to the importance of weed management in flax production systems.

Summary

Clearly, weed competition was the most important factor affecting flax performance. As flax seed and straw yield tended to be superior under weed-free conditions, the importance of sufficient weed control strategies in flax production is apparent. Without weed competition, the applied N is more available to flax, which improves yield potential. Producers should select fields with a history of low weed pressure when growing flax, especially if organic production is considered as regulations would prohibit chemical weed management. Moreover, producers should exercise caution when applying N to flax, as N was found to unfavorably benefit weed competition. Applying N as compost tended to result in the greatest amount of weed biomass. It is possible that more N in the compost was plant available than anticipated resulting in greater weed growth. Nitrogen did have an effect on flax as seed and straw yield increased with N in 2007, but only under weed-free conditions in 2008. Linolenic acid (omega-3 fatty acid) concentration of seed oil, however, was reduced by N and regardless of weed competition. Late seeding and prolonged moist field conditions in 2008 contributed to lower yields and the general lessened response to N source and N rate that year. **BC**

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Table 3. Weed biomass in weedy subplots as affected by N source and N rate in 2007 and 2008. Ames Iowa.

	--------- 2007 ---------				--------- 2008 ---------			
	N rate, lb N/A				N rate, lb N/A			
N source	0	30	60	90	0	30	60	90
	-------------------------- lb/A --------------------------							
Compost	4,050	5,560	6,750	12,280	3,940	3,300	4,040	7,610
Manure	4,050	4,580	4,200	4,480	3,940	5,310	6,370	7,030
Urea	4,050	4,770	5,160	4,520	3,940	5,600	5,850	6,830
Source of variation	------------------ p value -------------------							
N source (S)	0.0002				0.2530			
N rate (R)	0.0160				0.0057			
S x R	0.0082				0.4622			

Managing Degraded Soils with Balanced Fertilization in Zimbabwe

By Leonard Rusinamhodzi, Marc Corbeels, Shamie Zingore, Justice Nyamangara, and Ken E. Giller

Results from a long-term study showed that maize yields on depleted soils were marginally increased with multi-nutrient fertilizer application, while N fertilizer application alone resulted in lower yields on both sandy and clay soils. However, largest maize yields after nine seasons were achieved with cattle manure + fertilizer N application.

Low and declining soil fertility are recognized as major factors underlying low crop productivity in sub-Saharan Africa (Sanchez, 2002). Complex spatial and temporal variability in soil fertility associated with different soil types and contrasting management practices on different fields pose challenges for developing appropriate nutrient management recommendations.

On depleted soils, balanced nutrient management provides an opportunity to not only increase crop productivity, but also provides an option for rebuilding soil organic matter. This article outlines results from a long-term experiment conducted in northeast Zimbabwe. Its objective was to assess the long-term impact of various nutrient management practices on maize productivity within the contrasting soil types and regional management histories.

Two farms were selected for the study—one with a sandy soil (85% sand and 13% clay) and the other with a clay soil (42% sand and 44% clay). On each of these farms, two fields were selected with contrasting soil fertility conditions based on management history. One field had received annual additions of at least 5 t/ha manure and 50 kg/ha of N fertilizer, while the other field had been cultivated continuously with no manure and very little fertilizer (i.e., <10 kg N/ha). The four fields had variable soil properties and were classified as: standard sandy soil (SS); depleted sandy soil (DSS); standard clay soil (CS) and; depleted clay soil (DCS). Initial characterization showed that all soils were low in organic matter and available P, whereas K was deficient only in the sandy soils (**Table 1**). Experimental treatments were laid out in a randomized complete block design with three replications on 6 m × 4.5 m plots in each field. The experiment was run for nine consecutive seasons starting with the 2002-2003 season, with one crop of maize each year. Treatments included: (a) control (no fertilizer and/or manure added); (b) 100 kg N/ha; (c) 100 kg N/ha + 15 t manure/ha (i.e., fertilizer N + manure application, with manure adding about

Abbreviations and notes: N = nitrogen; AN = ammonium nitrate; SSP = single superphosphate; P = phosphorus; Ca = calcium; Mg = magnesium; Fe = iron; Cu = copper; Mn = manganese; Zn = zinc; CEC = cation exchange capacity.

Effects of manure + N on maize productivity on a depleted sandy soil.

Table 1. Initial and final soil chemical properties after nine seasons of manure and mineral fertilizer application on different soils and field types in Zimbabwe.

Soil	Field type	Treatments	C, %	N, %	pH	Available P, mg/kg	CEC, cmol$_c$/kg	Ca, cmol$_c$/kg	Mg, cmol$_c$/kg	K, cmol$_c$/kg	BS[1], %
Sandy	Standard	Initial	0.50	0.04	5.10	7.2	2.2	0.9	0.32	0.21	73.0
		Control	0.40	0.03	5.38	6.6	2.5	1.5	0.45	0.17	57.9
		100N	0.29	0.03	5.26	8.9	2.8	1.1	0.35	0.15	57.8
		100N + 15t manure	0.50	0.04	5.29	8.4	4.8	1.9	0.65	0.31	61.5
	Depleted	Initial	0.30	0.03	4.90	2.4	1.6	0.3	0.19	0.11	37.0
		Control	0.34	0.03	5.00	2.0	3.3	0.9	0.36	0.10	45.8
		100N	0.30	0.03	5.08	4.3	2.8	0.9	0.34	0.12	51.7
		100N + 15t manure	0.39	0.03	5.12	8.4	3.9	1.3	0.49	0.21	53.2
Clay	Standard	Initial	1.40	0.08	5.60	12.1	24.2	11.5	6.20	0.80	78.0
		Control	1.38	0.05	6.44	10.4	19.6	10.3	5.38	0.67	83.1
		100N	1.37	0.05	6.47	10.9	22.8	11.5	8.76	0.58	87.8
		100N + 15t manure	1.63	0.08	6.52	15.4	24.3	12.9	7.94	1.24	90.5
	Depleted	Initial	0.80	0.05	5.40	3.9	22.0	8.4	6.30	0.30	68.6
		Control	0.67	0.05	6.46	3.8	20.3	8.1	6.07	0.51	73.0
		100N	0.76	0.06	6.52	4.3	27.9	14.7	10.52	0.49	90.5
		100N + 15t manure	0.87	0.06	6.51	10.0	28.1	14.6	10.32	0.82	89.0
		SE[1]	0.11	0.00	0.14	0.84	2.51	1.28	0.92	0.09	3.82

[1]BS = Base Saturation; SE = Standard Error.

to 30 kg P/ha); and (d) 100 kg N/ha + 30 kg P/ha + 25 kg S/ha + 20 kg Ca/ha + 5 kg Mn/ha + 5 kg Zn/ha (i.e., multi-nutrient fertilizer application).

Mineral N fertilizer was applied using AN (34.5% N) and other fertilizer nutrients (P, Ca, Mn and Zn) were applied using a blend of SSP, and sulfates of Ca, Mn and Zn, which together with SSP supplied S. Aerobically composted cattle manure was applied annually on a dry-weight basis. To reduce vari-

ability, cattle manure was collected from the same farm every year and was generally of medium quality with a C:N ratio of 25 and contained macro- and micronutrients as follows: 1.1% N, 0.18% P, 0.20% Ca, 0.08% Mg, 0.64% K, 800 mg Fe/kg, 22 mg Cu/kg, 280 mg Mn/kg, and 112 mg Zn/kg. Manure was spread evenly on the surface covering the whole plot and incorporated into the soil (0 to 20 cm) using hand hoes before planting. Basal and top-dressing fertilizer was spot-applied
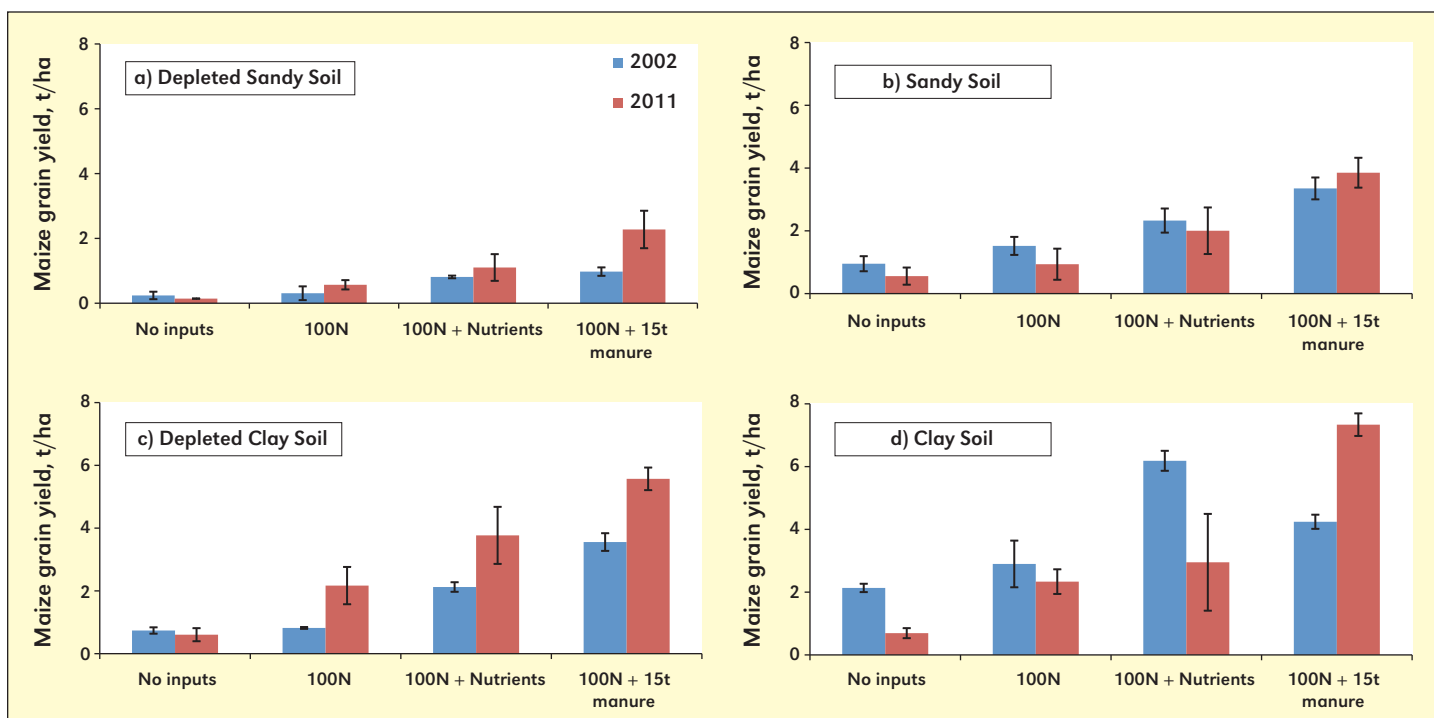

Figure 1. Initial and final maize yields and yield responses to long-term application of manure and mineral fertilizers under variable soil fertility conditions in Zimbabwe. Bars represent standard error of means.

Table 2. Gross margins with different fertilizer and manure application treatments under variable soil fertility conditions in Zimbabwe.

Soil type	Field type	Treatment	Yield, t/ha 2002/03	Yield, t/ha 2010/11	Cost of seed and fertilizer, US$/ha	Gross Margin*, US$/ha 2002/03	Gross Margin*, US$/ha 2010/11
Clay	Standard	Control	2.13	0.69	55	745	205
		100N	2.90	2.33	246	840	629
		100N + multi-nutrient fertilizer	6.18	2.95	376	1,943	730
		100N + 15t manure	4.24	7.34	741	849	2,009
	Depleted	Control	0.74	0.60	55	221	171
		100N	0.82	2.17	246	61	567
		100N + multi-nutrient fertilizer	2.12	3.77	376	420	1,037
		100N + 15t manure	3.56	5.57	741	592	1,347
Sandy	Standard	Control	0.95	0.56	55	302	153
		100N	1.52	0.94	246	323	104
		100N + multi-nutrient fertilizer	2.33	2.00	376	496	374
		100N + 15t manure	3.35	3.85	741	515	703
	Depleted	Control	0.24	0.14	55	34	-1
		100N	0.31	0.57	246	-130	-32
		100N + multi-nutrient fertilizer	0.81	1.10	376	-72	37
		100N + 15t manure	0.98	2.28	741	-375	112

*Gross margins were calculated using the farm gate price of maize grain of US$375/t and costs of 1 kg of N applied as ammonium nitrate = US$0.63; 1 kg of P supplied as multi-nutrient fertilizer blend = US$4.3; 1 t of manure = US$33; 1 kg of maize seed = US$2.2.

at each planting hill. Ammonium nitrate was applied as top-dressing in two 50 kg N/ha amounts at three and six weeks after crop emergence in all plots except the control. A medium maturity, drought tolerant hybrid maize cultivar (SC525) was planted at a spacing of 90 cm × 25 cm. All plots were weeded manually four times during each season. Gross margins for the different fertilizer treatments on each field were calculated by subtracting the cost of inputs (seed, manure and fertilizer) from the value of the maize produced.

Effects of Balanced Nutrient Management on Maize Productivity

Maize yields in control plots were lower in sandy soil than clay soil, and in the depleted fields (DSS and DCS) compared to un-depleted CS and SS, respectively (**Figure 1**). This was associated with lower indigenous nutrient supply capacity in the sandy versus clay-textured soils, and the depleted versus undepleted soil fertility.

Balanced fertilizer application increased yields in the long run in all soil types, except in sandy soils, where the increase was marginal. Fertilizer application alone, however, decreased maize yields in SS and CS over the nine cropping seasons. In the CS, larger maize yields were produced in the first year (2002) with mineral fertilizers alone than the fertilizer N + manure treatment, but this trend was reversed after nine seasons (**Figure 1d**). The lower yields with fertilizer after nine seasons were associated with lack of K application and removal of all crop residues after harvesting.

The results showed that the four field types we studied followed different pathways in rebuilding soil fertility as shown in maize grain yield trends. Although fertilizer is considered critical for sustainable crop production, the potential to restore soil fertility on the DSS through application of fertilizer alone was very poor. This is an example of the deviation between the pathways of soil fertility decline and restoration, which often act as a disincentive to smallholder farmers because building up soil fertility takes much more time than is required to deplete it (Tittonell et al., 2012). The small response in soil fertility build-up was more pronounced on the depleted sandy soils due to a combination of previous inadequate nutrient management and inherent infertility. In these soils, manure in combination with N fertilizer application was necessary to prevent long-term decline in yields as there was an increase over time in the yield difference between mineral fertilizer alone and fertilizer N + manure management strategies.

Crop yields with fertilizer N + manure were always larger than with mineral fertilizer alone at equivalent P application rate in sandy soils; this could have been due to K deficiencies. Potassium availability was especially poor in the sandy soils (**Table 1**), but was not included in the fertilizer alone treatments due to a general lack of K fertilizer in the region. Results suggested that manure + fertilizer N application proved better to mineral fertilizer application alone due to an increase in (a) the soil organic carbon and (b) the supply of K. A large portion of P and K in manure is often inorganic, thus manure is a good source for these nutrients (Eghball et al., 2002).

Effects of Balanced Nutrient Management on Soil Properties

Compared with the initial values, soil fertility generally declined with fertilizer application alone during the experimental period, except for a few elements like available P, Ca and Mg (**Table 1**). However, long-term application of manure versus N fertilizer alone increased or maintained the N concentration in all soil types, greatly increased available P, especially in depleted soils, and increased CEC and base cations, with more pronounced effects observed in sandy soils compared to the clay soils. Available P was kept near its initial level in

Variability in crop productivity within a smallholder farm in Zimbabwe.

non-depleted sandy soil, due to its history of receiving manure. This result contrasts with unmanured, depleted sandy soil that had very low initial P and therefore a net gain in P fertility. Soil organic carbon content greatly increased with fertilizer N + manure application treatment compared to the fertilizer treatment alone, especially in sandy soils.

Economic Benefits of Balanced Nutrient Management

The initial negative gross margins for all treatments with fertilizer in the DSS reflected a low yield response to N and manure application (**Table 2**). This indicated a clear disincentive for famers to target nutrient resources to DSS. Despite the low soil fertility status, the gross margins were positive in the DCS, highlighting better prospects for targeting nutrient resources to DCS for improved productivity.

Gross margins with manure + fertilizer N application were far greater than the margins with fertilizer application alone, especially in depleted soils after nine seasons (**Table 2**). Although the use of manure (15 t/ha) in combination with 100 kg N/ha was the most profitable, the cost was more than double the investment cost in the optimum fertilizer treatment. This coupled with the generally small quantities of manure available to smallholder farmers could be a barrier to the benefits reported here. A regional program to supply fertilizers with N, P_2O_5 and K_2O would likely be of greater benefit to smallholder farmers on sandy soils. Nevertheless, the results showed clearly the need for improved targeting of balanced nutrient management strategies for increased profitability of crop production in the highly variable soil fertility conditions on smallholder farms (Wairegi and van Asten, 2010).

Summary

Maize yields and yield responses to fertilizer and manure application varied depending on soil type and management history. Productivity was very poor on a depleted sandy soil and gross margins for manure and fertilizer application were low, highlighting challenges for increasing productivity in degraded soils that cover large areas of croplands in sub-Saharan Africa. Multi-nutrient fertilizer application led to great increases in maize yields over N alone. However, in situations where K was not applied and crop residues removed, the highest attainable yields and gross margins in the long-term were achieved with a combined application of fertilization N and manure. **BC**

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We live in an age of information overload, with an avalanche of information arriving each day. It can become a struggle to decide what information to accept and listen to, or judge which new ideas can be disregarded.

Getting reliable agronomic information is a challenge for everyone. We are all looking for innovations that will help improve efficiency and profitability. Plant nutrition products are evaluated for safety and for concerns arising during manufacturing and shipping, but there are no labels that tell you if they will work in your individual situation.

Several recent surveys of farmers from across the U.S. confirm the fact that crop advisers are the most frequently consulted source of agronomic information. Although the specific questions vary across regions and crops, farmers consistently look to their trusted adviser to help them sift through the information to get to the truth.

Given this critical role, it is essential to maintain that trust by staying current with the latest developments in agronomic science. This can be done through activities such as reading the latest trade journals and magazines, attending educational seminars, and asking probing questions. Practicing successful agronomy and horticulture requires assessing all the resources available and then using your experience to sort out what will work locally. For example, do you know how to implement the 4R's of Nutrient Stewardship in each field where you work? Can you clearly explain the cropping decisions you recommend if asked by a member of the general public?

Many new alternative fertilizer products have been introduced in the past decades. Some of these new products are based on sound science and their performance has been carefully evaluated in various scenarios. There are other products that have not been tested in a scientifically credible way, and they lack results that are explainable and reproducible. Instead, many of these products simply rely on endorsements and testimonials as a substitute for good science and statistical analysis.

Economic and environmental pressures on farmers seem to increase every year. Crop advisers have the unique opportunity to directly influence the success of farmers by providing the best possible information. The relationship of trust between farmer and adviser is reinforced each time accurate and useful information is transferred.

Certified Crop Advisers are tested to demonstrate proficiency in the areas of nutrient management, soil and water management, pest management, and crop management. Additionally, they are required to take 40 hours of continuing education every two years to keep current with the latest agronomic developments.

Whether you are a Certified Crop Adviser or any other type of farm adviser, remember that you are viewed as a trusted source of information in your community. Now you need to maintain your reputation by staying current in providing accurate and reliable agronomic information.

BETTER CROPS

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