BETTER CROPS
WITH PLANT FOOD

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2016 Number 3

Assessing the Potential Value of Organic Nutrient Sources in China

In This Issue...

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BETTER CROPS WITH PLANT FOOD

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Our cover: Maize seedling amidst conserved wheat stubble, Hebei, China.
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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 thanks the Government of Saskatchewan for their support of this publication through its resource tax funding.

2016 Annual IPNI Program Report: Connections, Leadership, and Building Partnerships

Available at http://ipni.info/PROGREPORT-2016

IPNI is a small organization with 32 Ph.D. level scientists and 30 support staff covering 13 program areas. We do not have laboratories, greenhouses, field equipment, or research facilities, nor are we affiliated with a university or college, but we are recognized and respected as a research and education institute. We have a mandate to develop and promote scientific information about the responsible management of plant nutrition.

One of our goals is to provide collaborative leadership development on global plant nutrition development issues. We accomplish this by our worldwide presence and developing alliances with strategic partners. Our scientists actively participate in their national professional organizations and scientific societies, and often hold leadership positions within those organizations. This type of participation gives us a voice and allows us to provide direction and influence. It provides our partners exposure to and familiarity with the fertilizer industry and the challenges we face as we strive to do our part in supporting global food security and nutrient stewardship.

In 2016, our Program Report focused on these relationships using a theme of Connections, Leadership, and Building Partnerships. We have a vast network of academics and professionals that we interact with. We work to cultivate their friendship, their collaboration, and their respect. In so doing, they become our advocates in their organizations, in their communities, and in the public as they have opportunities to discuss the role and challenges of fertilizers in global food security, sustainability, and climate smart agriculture. These connections allow IPNI to expand our efforts and leverage our resources.

This year our digital format of our Program Report allows us to provide a selection of short video highlights … just a few examples of our many regional collaborations across the world.

Dr. Terry Roberts, IPNI President

IPNI Board of Directors Elects New Officers

The IPNI Board of Directors has elected its new executive officers during its meeting held in Moscow, Russia this May, 2016.

Mr. Norbert Steiner, Chairman of the Board of Executive Directors of K+S Aktiengesellschaft, Kassel, Germany was elected as the new Chairman of the IPNI Board. Mr. Tony Will, CEO of CF Industries Holdings, Inc., Deerfield, Illinois, USA, was elected Vice Chair. Mr. Dmitry Osipov, CEO of Uralkali was elected Chair of the Finance Committee.

"We look forward to continued great leadership from our Board and working committees," said Dr. Terry Roberts, President IPNI.

Mr. Norbert Steiner, Chairman of the IPNI Board

Mr. Tony Will, Vice Chair of the IPNI Board

Mr. Dmitry Osipov, Chair of the Finance Committee

Estimation of Organic Nutrient Sources and Availability for Land Application

By Shutian Li, Xiaoyong Liu, and Wencheng Ding

Knowledge of the status and characteristics of organic nutrient resources in China is essential for their efficient management in agricultural production.

Provincial and regional level estimates are provided for the amount of organic wastes, their nutrient supply capacity, as well as their availability to cropland.

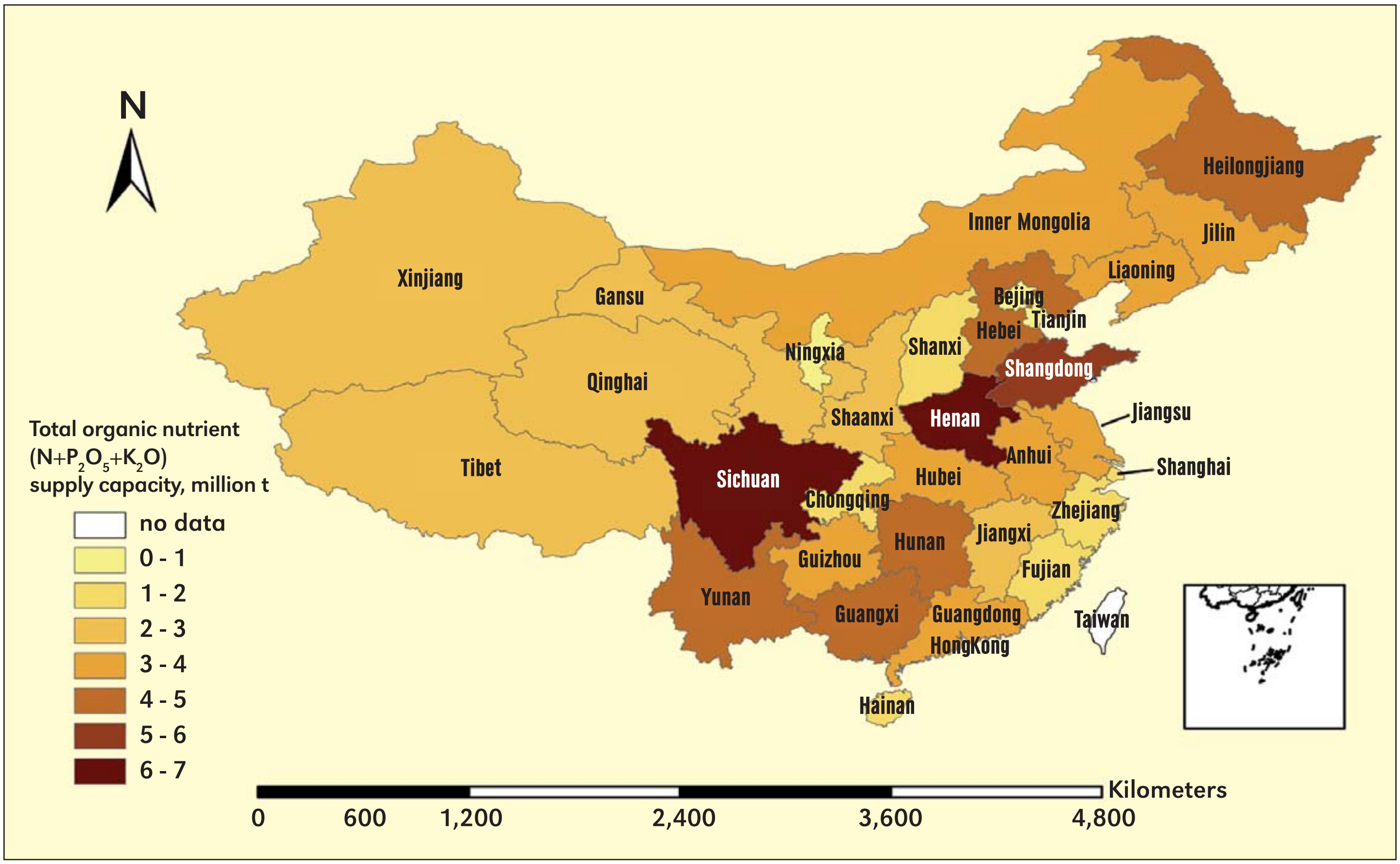

Figure 1. Total organic nutrient supply capacity by province in China in 2013. Nine provinces show capacities above 3 M t of $N+P_2O_5+K_2O$. Li et al. 2016

Great increases in Chinese crop production and livestock farming have in turn produced large amounts of nutrient-laden animal wastes and crop residues. Organic wastes from human activities, and of legume manures are also viewed as valuable organic resources. The recent government policy of "zero growth by 2020" for fertilizer sources is increasing the focus on how all available nutrient sources can be used best. Part of this focus is placed on an increased interest in using organic nutrient sources, like livestock manure, to offset inorganic fertilizer use. The estimation of the nutrient supply capacity and availability from these organic resources is important for understanding nutrient input/output balances in the Chinese agricultural system, and will have a great effect on nutrient management and fertilizer application in China.

Abbreviations and notes: N = nitrogen: P = phosphorus: K = potassium; MLY = middle/lower reaches of Yangtze River.

As a whole, the total organic resource in China amounts to more than 5.0 billion t in fresh weight (Li et al., 2016). This total product amounts to 79.7 million (M) t of NPK nutrients including 31.7, 14.4, and 33.6 M t of N, P_2O_5, and K_2O, respectively. This represents an amount similar to the N and P_2O_5 that was applied via fertilizers during 2013 in China, while the organic K_2O total is almost four times that applied as fertilizer that year. Sichuan, Henan, and Shandong have been the top three provinces in terms of organic nutrient supply capacity—each with more than 5 M t (**Figure 1**).

The contribution of the various organic sources, relative to all organic resources, varied greatly among provinces. Animal waste has accounted for 28 to 96% (mean of 50%) of the total organic nutrient resources, straw was 2.3 to 56% (mean of 31%), human excreta was 1.2 to 48% (mean of 18%), and legume green manure was less than 5% (mean of 1.5%).

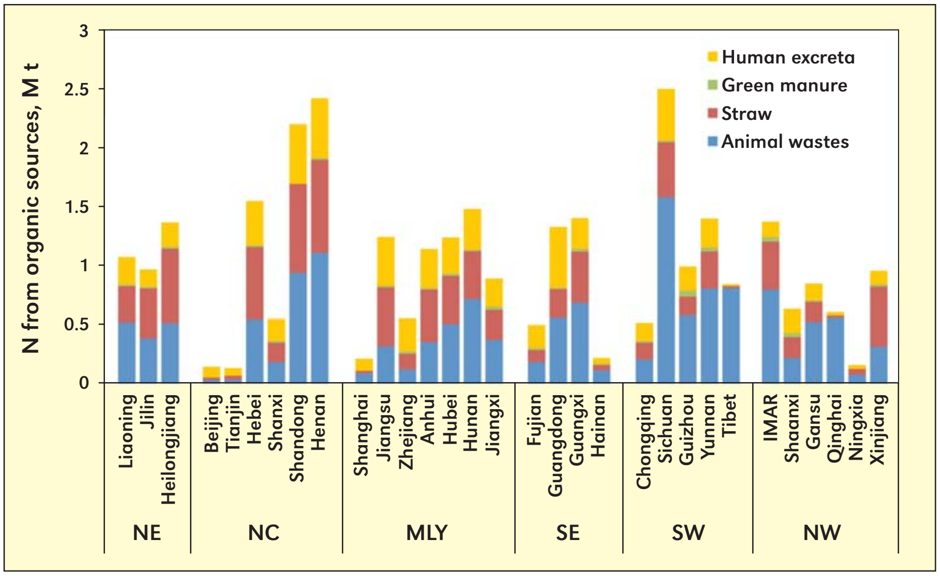

Figure 2. Total amount of nitrogen from different organic sources in 2013 assuming zero losses. Li et al. 2016.

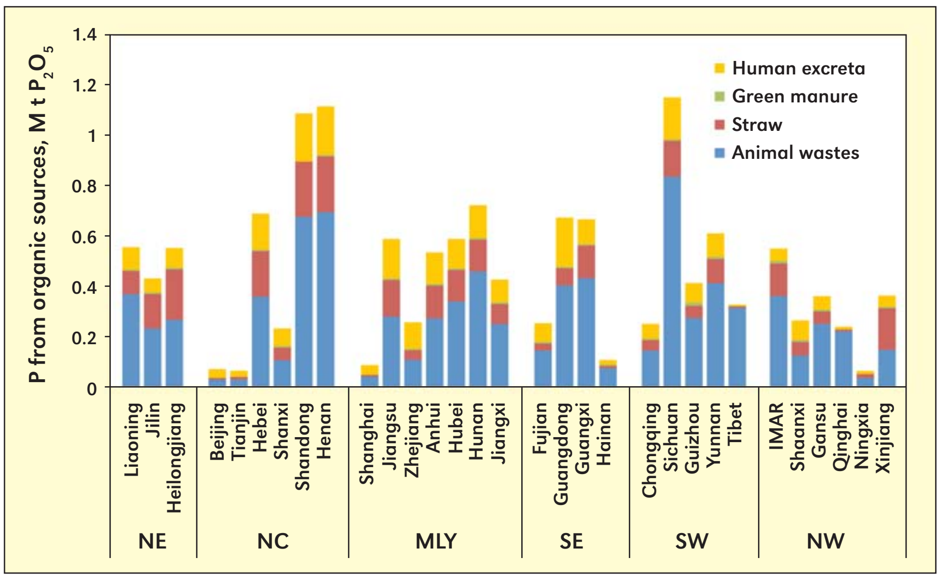

Figure 3. Total amount of phosphorus from different organic sources in 2013. Li et al. 2016.

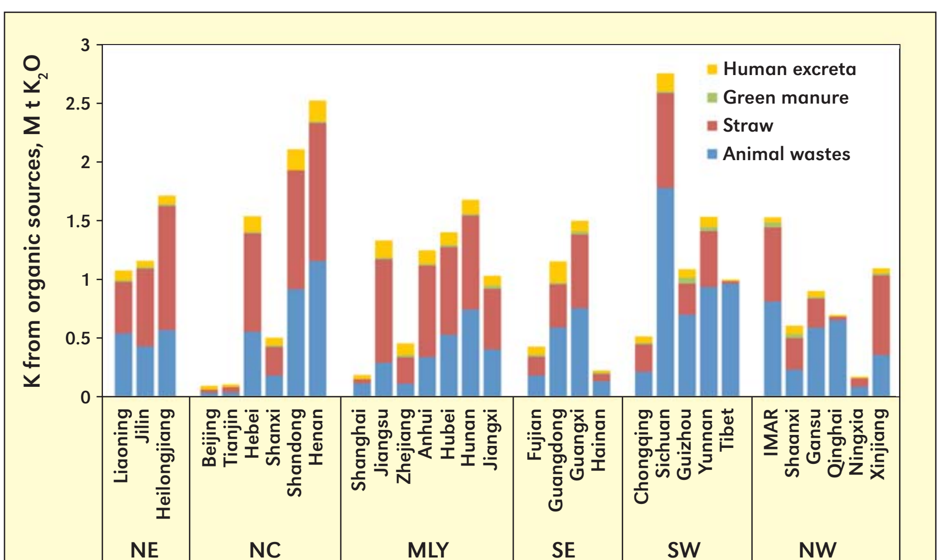

Figure 4. Total amount of potassium from different organic sources in 2013. Li et al. 2016.

Characteristics of Organic Nutrients and Their Regional Availability

There are large differences in the organic N sources that are present within the distinct regions in China (**Figure 2**). In the northeast region, organic N is mainly from animal manures (42%) and crop residues (39%). In the northwest and southwest regions animal manure is the main N source, accounting for an average of 55% and 64% of total organic N sources, respectively. In north central and southeast China, and the middle/lower reaches of the Yangtze River, crop residues and human excreta are the main N sources in addition to animal manures, accounting for 58%, 61%, and 53% of the total organic N, respectively.

Animal wastes are the main source of organic P in all provinces (**Figure 3**). Comparing regions, the northeast, north central, middle/lower reaches of the Yangtze River, southeast, southwest, and northwest had 57%, 58%, 55%, 62%, 72%, and 62% of its organic P originating from animal manures.

Potassium is the most significant nutrient contained within organic nutrient sources, mainly animal manures and crop residues (**Figure 4**). In the northeast, north central, and the middle/lower reaches of the Yangtze River regions, straw K represented 54%, 48%, and 54% of the total organic K resource. While in the southeast, southwest, and northwest regions, animal wastes were the main organic K source, accounting for 51%, 67%, and 55% of the total.

Considerations for Organic Nutrient Resources

If properly used these organic nutrient resources would be appropriate substitutions for fertilizers, especially in the case of potash. However, the potential for mismanagement of these organic sources can be high given traditional application practices, and there are significant risks towards serious environmental issues for China's surface and shallow water sources from both over application of organic materials, and the heavy metal loading common in some of these waste products. Organic wastes are mainly applied to land directly or as composts within an area near their origin because of the associated transportation costs. Only a small portion of these organic wastes are used to produce commercial organic-inorganic

Limited carry-over of maize residue, leaving minimal crop stubble, has been common in Hebei Province where the majority is removed and used for other purposes.

Returning maize straw back to cropland in Jilin Province.

fertilizer that can be transported across regions.

These estimates of organic sources and nutrient capacity/availability can vary considerably based on parameters such as daily excrement of livestock animals, nutrient content of manures, and the proportion of manure/crop residues that can be returned to land. Although these estimates show there are very large organic nutrient resources available in China, the potential for nutrient losses during storage and processing, especially for manure N, is also large and seemingly unavoidable. The amount of recoverable organic nutrient that is available to be returned to cropland varied greatly among provinces (**Figure 5**). Amounts ranged from 0.04 to 0.92 M t N, 0.03 to 0.66 M t P_2O_5, and 0.05 to 1.41 M t K_2O for individual provinces, with a total of 9.5, 7.1, and 16.2 M t for N, P_2O_5, and K_2O for China.

It is estimated that the percentage of organic nutrient N, P_2O_5, and K_2O returned to cropland was 18 to 38%, 39 to 64%, and 37 to 62% of the total supply capacity for individual provinces, with an average of 30%, 49%, and 48% nationally. These data suggest that more than half of the total organic nutrients are not recycled to agricultural land. A concerted effort is needed to increase the use of organic nutrients and balance their use with fertilizers, but this will require both scientific and policy support.

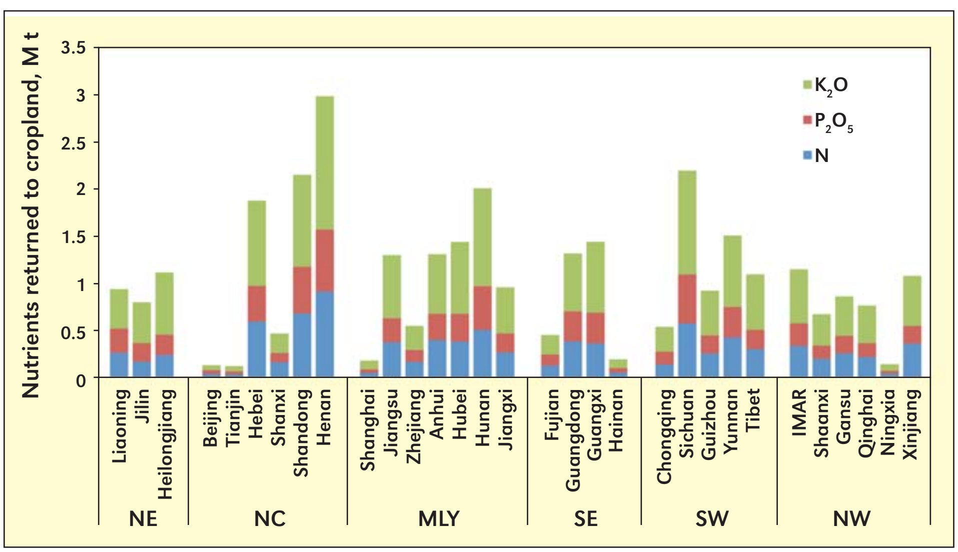

Figure 5. The amount of organic nutrient N, P_2O_5, and K_2O returned to cropland in 2013. Li et al. 2016.

Summary

China has sufficient organic sources with a nutrient-supplying capacity that exceeds recent totals for fertilizer consumption. The challenge of recovering these nutrients, transporting them, addressing the challenge of accumulated heavy metals, and applying them uniformly across agricultural lands still remains. Regardless, China's organic nutrient sources could make a significant contribution to the current policy promoting a zero increase in fertilizer consumption by 2020. Every effort should be made to try and capture 50% or more of these organic nutrients that are currently not being returned to croplands. BC

Dr. Li (e-mail: sli@ipni.net) is a Deputy Director, IPNI China Program, Mr. Liu is a Ph.D. student and Mr. Ding is a M.Sc. student at the Graduate School of the Chinese Academy of Agricultural Sciences in Beijing, China.

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Fertilization Impacts on Productivity and Profitability of Potato

By Hirak Banerjee, Sudarshan Dutta, Lalita Rana, Krishnendu Ray, Sukamal Sarkar, and Kaushik Majumdar

Economically viable potato production in West Bengal, India relies on balanced fertilizer management to build high yields of quality product, and return a strong economic response.

This study supported recommended NPK application rates as a means of increasing the proportion of superior grade potato and optimizing economic returns to farmers.

N was the most limiting nutrient, followed by P and then K. Over (150%) or under (50%) application of NPK showed no advantage to potato quality or economic returns.

Potato is one of the major staple crops produced throughout the world. The average potato yield in countries such as U.S., Germany, Netherlands, and France range between 38 to 44 t/ha, while in India it is only 23 t/ha (FAOSTAT, 2015). Three states, Uttar Pradesh, West Bengal, and Bihar, jointly contribute about 78% of the total potato production in India. West Bengal is the second largest potato growing state in India, producing 13,400 t from 409,000 ha—an average productivity of 24 t/ha (Govt. of West Bengal, 2012).

The major constraints for higher yield of potato in the state are inadequate and unbalanced nutrient use (Mozumder et al., 2014). Along with temperature variation, nutrient management plays a major role in potato yield improvement in West Bengal. Nitrogen, P, and K requirements of potato are high (Zewide et al., 2012), and optimum supply of these nutrients improves yield and quality of potato tubers where native soil supplies are limited (Westermann, 2005). These nutrients are key to optimum plant growth and are also essential for regulating plant water status and osmotic pressure, increasing nitrate reductase activity, and raising photosynthesis and transpiration (Li et al., 2011). Nitrogen influences yield by increasing the size and the number of tubers. Phosphorus is the second most limiting nutrient and influences root and shoot growth, as well as the rate of tuberization. Potassium plays an important role in increasing tuber size, yield, and quality. Potassium uptake by potato is high, and it plays a significant role in translocation and accumulation of photosynthates (carbohydrates) from the leaves to the tubers. Deficiencies of the major nutrients limit potato plant canopy growth and its duration, resulting in reduced carbohydrate production and tuber growth.

This potato field trial was carried out in 2012–13 and 2013–14 on alluvial soils in the Hooghly District of West Bengal (**Figure 1**). The objective of the study was to generate information on phenological and productivity changes with varied NPK levels. The experimental soil was clayey in texture, with 0.1 dS/m EC, 0.78% organic matter, pH of 6.2, and 180 kg/ha available N, 24 kg/ha available P_2O_5, and 210 kg/ha available K_2O. The available N was analyzed through the hot alkaline permanganate method. Available P was extracted with 0.5 M $NaHCO_3$ (pH 8.5) and measured through a UV-VIS spectrophotometer. The available fraction of K was extracted with neutral normal ammonium acetate (pH 7.0; 1:10 w/v) solution and estimated through a flame photometer. Maximum and minimum air temperature fluctuated between 36°C and 7°C in 2012–13; 34°C and 9°C in 2013–14. Total rainfall during the experiment (November to March) was 46 mm (5 rainy days) and 55 mm (2 rainy days) in 2012–13 and 2013–14, respectively. The experiment included seven treatments: T_1 (50% NPK), T_2 (100% NPK), T_3 (150% NPK), T_4 (100% PK), T_5 (100% NK), T_6 (100% NP), and T_7 (control without NPK). The 100% NPK treatment provided 200-150-150 kg N-P_2O_5-K_2O/ha, which was the state recommendation (SR). Potato seed pieces (cv. Kufri Jyoti) were planted at a spacing of 60 × 20 cm at a depth of 15 cm. All P and K fertilizers were applied prior to sowing, while N fertilizer was applied in two splits—50% before sowing and 50% at 30 days after planting (DAP). Treatment means were

Abbreviations and Notes: N = nitrogen; P = phosphorus; K = potassium.

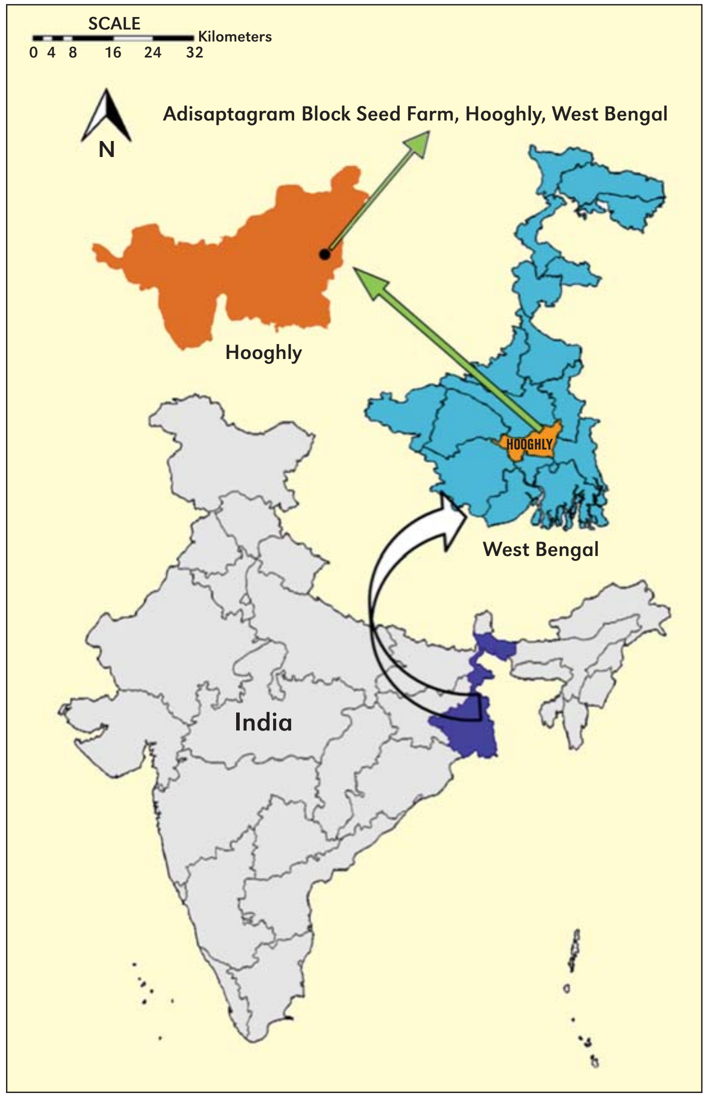

Figure 1. Location of the experimental site (23°26° N and 88°22° E with an elevation of 12 m above mean sea level).

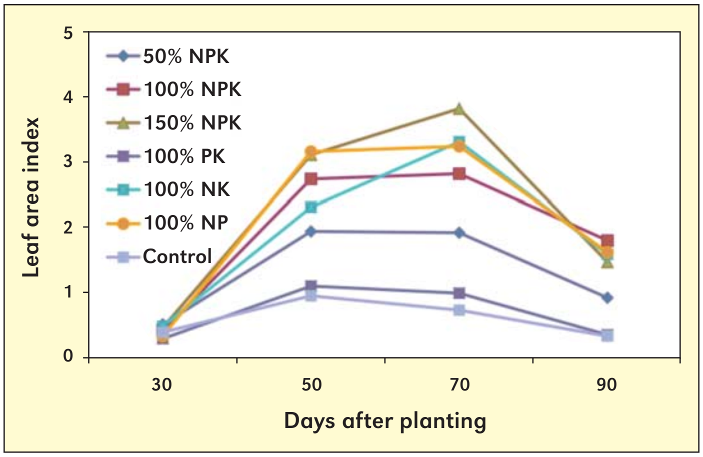

Figure 2. Leaf area index of potato plant over the crop season with varied NPK levels, West Bengal.

separated using a least significant difference (LSD) at the 0.05 probability level.

Impact on Growth, Yield, and Nutrient Uptake

Leaf area index (LAI) and dry weight per plant are considered the two major growth indicators of potato. These characteristics were measured at 30, 50, 70, and 90 DAP. LAI is calculated as the ratio of the measured leaf area of the plant to the ground area. NPK application significantly affected LAI at 30 DAP (**Figure 2**). Omission of N (100% PK) and control plots resulted in a significant reduction in LAI. The LAI of plants receiving 150% NPK declined sharply at 90 DAP, which indicates that NPK application at this rate produced more leaves but also led to early leaf senescence.

Dry weight per plant was determined by drying the entire sample plant to a constant weight at 70°C for 72 hours. Dry weight increased with crop age, and NPK rates significantly influenced the dry weight per plant (**Figure 3**). Factors such

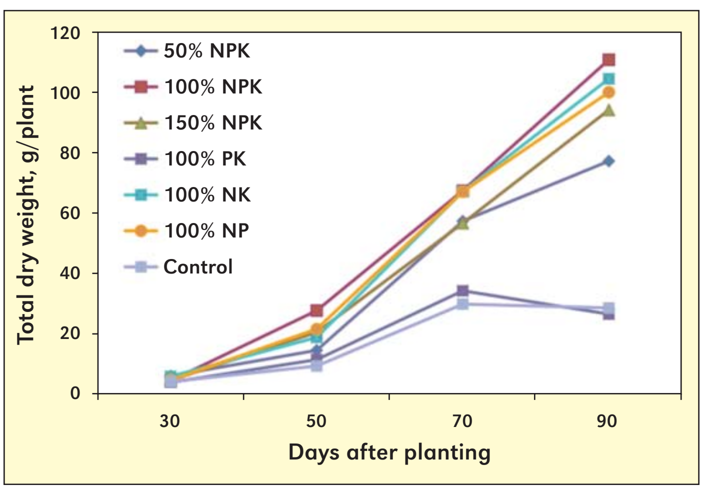

Figure 3. Total dry weight of potato plant (plant + tuber) over the crop season with varied NPK levels, West Bengal.

as maturity of tubers, and nutrient and water uptake by plants regulate dry matter production, while NPK fertilizer promote plant growth by extending the growing period. Under N omission and control treatments, total dry matter production was consistently low, reflecting the role of N in plant nutrient acquisition. Dry matter accumulation in potato was negatively

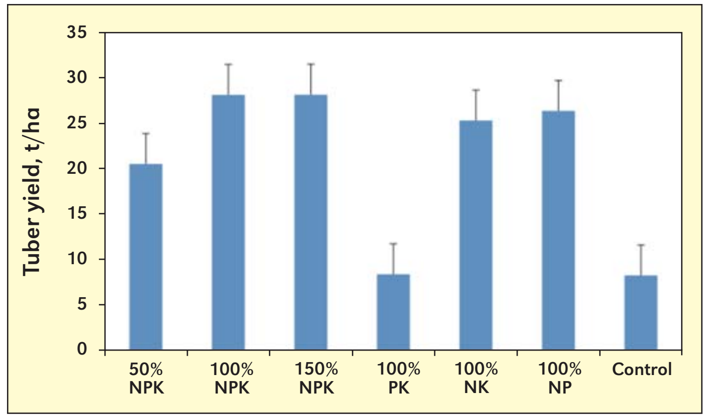

Figure 4. Tuber yield of potato with varied NPK levels, West Bengal.

influenced by N deficiency, but also in conditions when N supply was high.

NPK fertilization showed a positive influence on total tuber yield (**Figure 4**). Tuber yield increased with increasing levels of NPK. Application of 150% NPK produced the highest total tuber yield, although that was statistically at par with 100% NPK. The observed higher fertilizer response may be linked to the increase in total leaf area, that in turn increased the amount of intercepted solar radiation and supported more photoassimilates to produce more tubers (Banerjee et al., 2016). This increase in yield may also be attributed to better availability of nutrients, improved vegetative growth, and greater synthesis of carbohydrates and their translocation.

Potato yield was significantly reduced by nutrient omission. Respectively, omission of N, P, and K reduced tuber yield by 70, 10, and 6% when compared to the 100% NPK treatment. The significant yield reduction due to N omission might be partly attributed to greater reduction in plant growth and yield components, and highlights the importance of N in potato cultivation. Yield loss was higher for P omission than for K omission. The yield reduction due to K omission was rather small, which might be due to the medium K availability of the experimental soil, a reflection of the high K-supplying capacity of these alluvial soil types rich in illitic clays (Sarkar et al., 2013) as well as a history of K application. However, it should also be remembered that high yielding potato removes a significant amount of K from the soil and reduced or omission of K based on an over-reliance on soil K reserves leads to a loss in long term soil fertility.

Plant nutrient uptake was highest for K followed by N then P (**Figure 5**). Potato takes up considerable quantities

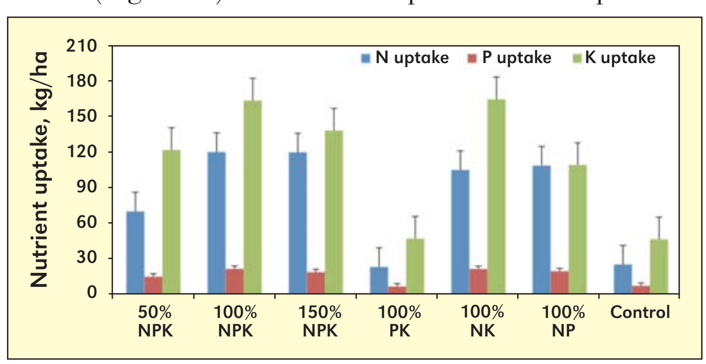

Figure 5. Nutrient (NPK) uptake by potato with varied NPK levels, West Bengal.

of K during the tuber bulking stage to generate yield with bigger tubers. The recommended fertilizer treatment (100% NPK) had significantly higher N uptake over the control and 50% NPK treatment, and was statistically at par with 150% NPK. Lowest N uptake in potato plant was observed under N omission and the control (80% and 79% less than with 100% NPK, respectively). Similar to N uptake, P uptake was higher with 100% NPK, and it did not differ significantly with 150% NPK. Significantly lower P uptake was observed in plants with 100% PK and control plots. Interestingly, the P uptake in N omission treatment was lower than with the P omission treatment. Nitrogen uptake in the 100% NPK treatment was significantly higher than the P and K omission plots that received 100% N. This highlights the importance of balanced P and K application in potato for optimum utilization of applied N. Potassium uptake varied significantly across treatments, but showed higher K uptake with 100% NPK (247% more than the control). Interestingly, N omission had a far greater impact on K uptake than K omission itself, corroborating the synergistic effect of balanced fertilization.

Table 1. Economics of potato production (Mean data of 2 years), West Bengal.

Treatments	Common cost, US$/ha/yr	Treatment cost, US$/ha/yr	Total cost, US$/ha/yr	Gross return, US$/ha/yr < 50g	> 50g	Total	Net return[1], US$/ha/yr	Benefit: Cost ratio
50% NPK	1,259	130	1,389	330	1,402	1,732	343	1.25
100% NPK[2]	1,259	216	1,475	285	2,252	2,537	1,062	1.72
150% NPK	1,259	374	1,633	292	2,241	2,533	900	1.55
100% PK (-N)	1,259	208	1,468	232	382	613	-855	0.42
100% NK (-P)	1,259	177	1,436	325	1,890	2,214	778	1.54
100% NP (-K)	1,259	127	1,386	326	1,994	2,320	934	1.67
Control (-NPK)	1,259	0	1,259	228	377	604	-655	0.48

[1] Net return = Gross return – Total cost; 1 US$ = INR 60 (Indian rupees); Market price for potato 100 US$/t
[2] State recommendation; Selling price of < 50g tubers is INR 150/bag and > 50g tubers is INR 300/bag (1 bag = 50 kg).

Economics

Net income and Benefit to Cost (B:C) ratio continued to increase up to 100% NPK, and further addition (150% NPK) resulted in a decrease of both (**Table 1**). These higher economic returns at 100% NPK are attributed to increased total tuber yield. Cost of cultivation only differed marginally on account of nutrient omissions but resulted in a significant reduction in the yield and net profit, especially for N and P omissions. Negative net returns were recorded in the control plots and N omission treatments. Omission of N reduced the net returns drastically, while P was the second most limiting nutrient. It is to be noted that although the omission of K did not significantly impact the B:C ratio because of the high K-supplying capacity at the site, the application of K fertilizer at the recommended rate helps maintain soil health by avoiding the depletion of the nutrient, which has long term implications on soil fertility and sustainable productivity (Majumdar et al., 2016).

Summary

In summary, potato responded positively to NPK fertilization. Total tuber yield increased with up to 150% of the state recommendation for NPK fertilizer application, and omission of nutrients led to reduced tuber yield. The study highlights that N is the most limiting nutrient for potato production in West Bengal, followed by P and K.

Acknowledgement

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Potato field at Adisaptagram Block Seed Farm, Hooghly, West Bengal, India.

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Analysis of Crop Nutrient Response Patterns to Guide Site-Specific Fertilizer Recommendations

By Job Kihara, Samuel Njoroge, and Shamie Zingore

- **Large field-to-field variability in maize response** to fertilizer additions indicates considerable differences in sub-Saharan African soil conditions.
- **Cluster analysis categorized results** from on-farm trials to determine the variability in soils and crop productivity.
- **The technique effectively separated responsive from non-responsive fields,** and further helps to identify the limiting factors to productivity.

Mr. Otieno (pictured) is part of a research team that is working to develop and disseminate site-specific nutrient management recommendations in sub-Saharan Africa.

Poor productivity of food crops due to low soil nutrient levels is a major contributor to food insecurity in sub-Saharan Africa (SSA) (Shapouri et al., 2010). Current investments to help farmers increase fertilizer use are not often supported by appropriate fertilizer recommendations (Giller et al., 2011), resulting in poor fertilizer use efficiency and low economic returns to investment in fertilizer (Nziguheba et al., 2009). Information that can help to target the right fertilizer source and application rates for specific crops and locations, is crucial for sustainable crop production intensification in smallholder farming systems.

Although crop fertilizer response categories based on the response, or lack of response, to nutrient application are generally recognized, there is currently no large-scale information on their occurrence, extent, distribution, or identifying soil property characteristics. This study was conducted across a range of sites in four countries in SSA to assess the prevalence and distribution of soil nutrients and soil constraints that limit crop productivity in major cereal-based cropping systems. It also had the objective of developing a simple system for classifying patterns of crop yield response to fertilizer. The study also determined the soil properties that characterize the classes of crop nutrient responses.

Nutrient omission trials for identifying soil fertility constraints were implemented in Kenya, Malawi, Nigeria, and Tanzania. In each country, between 23 and 49 on-farm locations were strategically selected to cover a wide range of soil conditions that are representative of high potential maize growing areas in East and West Africa. Field trials were conducted between 2009 and 2012. The field trials were implemented using a modified nutrient omission trial design (**Table 1**), with maize as the test crop (plant spacing was 0.75m x 0.25m). All field trials were designed and managed by researchers follow-

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Ca = calcium; Mg = magnesium; B = boron; Cu = copper; Fe = iron; Mn = manganese; Na = sodium; Zn = zinc; C = carbon; Al = aluminum; SOC = soil organic carbon; ppm = parts per million.

Table 1. Treatments implemented in Africa Soil Information Service (AfSIS) diagnostic trials.	
Treatment	Description
Co	Control (no nutrient added)
NPK	Macronutrients added
-N	P and K applied (N omission)
-K	N and P applied (K omission)
-P	N and K applied (P omission)
+MN	NPK+Secondary and Micro-nutrients (Ca, Mg, S, Zn, B)
+MA	NPK+manure
+L	NPK+lime

Nutrients were applied at rates of 100 kg N/ha, 30 kg P/ha, 60 kg K/ha, 10 kg Ca/ha, 5 kg Mg/ha, 5 kg S/ha, 3 kg Zn/ha, and 3 kg B/ha. Manure was applied at 10 t/ha on a dry matter basis and lime at 500 kg/ha.

ing standard best agronomic management practices.

Soil sampling began at the start of the trials, before application of fertilizers and amendments. Soil samples were analyzed for major soil characteristics including organic C, total N, available P, S, B, Mn, Cu, Zn, K, Ca, Mg, Na, Fe, exchangeable Al, and pH. Crops were harvested at maturity in a net plot of 6.75 m^2 and grain yield was expressed on dry weight basis (12.5% moisture content).

Cluster analysis was conducted using K-Means clustering on the differences between the grain yield from a given treatment and the control treatment, to identify various classes of nutrient response patterns. A multinomial logit regression model was developed and used to identify the possible soil factors influencing the identified response clusters.

Four main clusters were identified as appropriate for categorizing observed nutrient responses. These clusters explained 60% of the variation in the yield data. Yields from the various treatments in each cluster were plotted (**Figure 1**), and the clusters were interpreted as followed:

Cluster 1: Fields where maize was not responsive to any nutrient application or soil amendments. The cluster was further disaggregated according to fertile soils (Cluster 1b in **Figure 1** referred to as fertile non-responsive fields) with high yields (attainable yield level between 4 to 5 t/ha) and infertile fields with low yields (Cluster 1a referred to poor non-responsive fields, attainable yield level remains below 2 t/ha) and have major limitations that need to be addressed before any nutrients or amendments can have any significant effect. 25% of the fields considered in this study were in this cluster.

Cluster 2: Fields with major N and P limitations and occasionally K limitations. Addressing N, P and/or K limitations results in yields up to 4 t/ha. The addition of manure further improved the yield substantially (by 40% over NPK), as well as adding multi-nutrients to the NPK (i.e., the +MN treatment) improved the yields significantly (by 23% over NPK). Average yields achieved with the appropriate inputs was about 5.5 t/ha. 36% of the fields fell into this cluster.

Cluster 3: Fields where maize had limited response to both nutrient application and further addition of amendments. While nutrient application increased yields, attainable yields were about 3 t/ha due to other constraints that limit yield response. 28% of the fields fell into this cluster.

Cluster 4: Fields with N as the major limiting factor. Maize was strongly responsive to N application but showed limited response to P and K. Addition of lime, multi-nutrients or manure further improve the yield. Attainable yield level with the appropriate macronutrient inputs is 5 t/ha, but can be increased to 6.5 t/ha with the required soil amendments. Fields in this cluster constitute 11% of the cases.

The majority of fields (36%) were located in Cluster 2, which showed a high response to N and P. This was in line with the general consensus in the region that N and P are the key limiting nutrients to crop production in SSA (**Table 2**). However, the high prevalence of poor non-responsive and low responsive soils in all countries indicate major challenges to increase crop productivity at large scale. The attainable yields in more than 50% of the fields were less than the first-step yield target of 3 t/ha. This target was set for the African Green Revolution in SSA (Sanchez, 2010) and is considered a realistic target when nutrient and other agronomic inputs are applied in adequate quantities.

Although only a small fraction of the fields were classified as non-responsive due to high fertility, such non-responsiveness is mainly expected in areas newly converted to cultivation or in fields close to homesteads that receive large applications of fertilizer and manure (Giller et al. 2011). The presence of these fields adds to the discourse on the need for site-specific

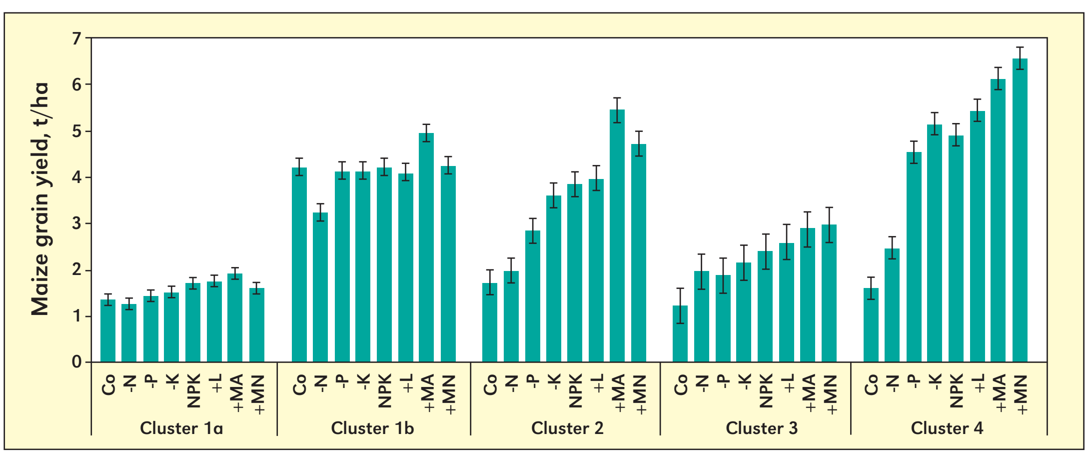

Figure 1. Maize grain yield observed from sub-Saharan Africa fields classified under different clusters following K-Means clustering. Error bars are standard errors of the estimates. Co = Control; -N, -P, -K = omission plots; NPK = macronutrients; +L = NPK+lime; +Ma = NPK+manure; +Mn = NPK+Ca, Mg, S, Zn, B.

Table 2. Occurence and soil properties of the main nutrient response clusters.

Variable	Cluster 1a (poor, non-responsive fields)	Cluster 1b (fertile, non-responsive fields)	Cluster 2 (fields responsive to N, P and manure)	Cluster 3 (low response fields)	Cluster 4 (fields highly responsive to N)
Fields per cluster, %	21	4	36	28	11
Soil properties					
pH	5.6	6.1	5.5	5.7	6.3
C, %	1.2	2.1	1.0	1.5	1.0
Ca:Mg	2.56	2.6	2.8	2.96	4.5
Na, ppm	24	26	30	31	37
P, ppm	17	11	11	18	46
Al, ppm	1,040	816	1,248	890	841
Mn, ppm	94	100	210	130	159
S, ppm	9.3	7.9	9.4	8.5	9.3
B, ppm	0.07	0.34	0.12	0.1	0.16
Zn, ppm	1.81	2.23	2.14	2.31	2.57

Soil property values represent the median. Critical lower limits (ppm) for micronutrients (DTPA extractable) are: Mn = 2; Fe = 4.5 (Sillanpaa, 1982); Cu = 1 (Lopes, 1980).

nutrient application based on individual field characteristics such as location, previous management, and farmer resource endowment. For example, fields in Cluster 2 may only require the application of fertilizer quantities geared at maintaining fertility in the short-term.

Soil data from the specific experimental fields within a site showed wide variability in major properties with median soil pH ranging from 5.2 to 6.4, and the available P from 3.6 to 52.8 mg/kg (**Table 2**). Cluster 4 was characterized by high responses to N and had very high levels of available P. The fields in the poor non-responsive category had the lowest Zn, B, Cu, Mn, and Na (**Table 2**). Using the poor non-responsive fields in Cluster 1 as the base category in the multinomial logit shows that increasing the soil Ca:Mg ratio is highly significant. As well, increasing soil contents of Zn, S, B, and Na, while simultaneously decreasing Al concentrations, was also significant. This required the poor non-responsive fields to move to the highly responsive category of Cluster 2, which is responsive to most of the nutrients and amendments. The poor non-responsive fields clearly had less C than the fertile non-responsive fields (1.4% vs. 2.0% C, respectively), in addition to the limitations due to low B and exchangeable bases.

The results from this study highlight the need for fertilizer recommendations that address the requirement of balanced fertilizer application, including micronutrients, under highly variable soil fertility conditions. Further, management of soils in SSA requires a clear distinction between those intermediate to highly responsive soils on the one hand, and the low to non-responsive soils on the other hand. For the responsive soils, the focus should be on optimizing management of inorganic nutrient inputs, including micronutrients, while maintaining soil organic matter management. For the low to non-responsive soils, attention should be placed on restoring the productivity through balanced nutrient management, improved soil water management, and application of organic resources to increase SOC and micronutrients in the medium term. It is important to highlight that significant crop productivity improvement in the short-term should not to be expected on these low and non-responsive soils (Zingore et al. 2008). Changes in land use, or selection of crops that are better adapted to degraded soils, could also be considered as options for rehabilitating degraded soils.

Summary

Current initiatives to intensify crop productivity in SSA are currently limited by the large variations in crop yield responses to applied nutrients observed between fields and regions. Analysis of data from multi-location nutrient omission on-farm trials indicates that maize crops in 11% of fields were highly responsive to N application, while 28% showed a low response and 36% showed an intermediate response to macro and micronutrients. A total of 21% of the fields were categorized as degraded and 'non-responsive' to any nutrient or soil amendment. Efforts to achieve sustainable crop production intensification in smallholder farming systems in SSA requires the development of management strategies which improve the efficient use of fertilizer and other cropping inputs. This work highlights the need for research to recognize the distinctive nutrient response patterns found on-farm in SSA, and to carefully consider their underlying soil properties.

Acknowledgement

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Proactive Stakeholder Program Measures On-farm Effectiveness of Conservation Practices that Reduce Fertilizer and Manure Nutrient Loss

By Andrew Sharpley, Mike Daniels, Larry Berry, Cory Hallmark, and Lee Riley

Livestock and crop agriculture are often cited as major contributors of nonpoint source (diffuse) losses of soil and nutrients to water resources.

Runoff losses of soil and nutrients from representative farm fields are being investigated under different conservation and nutrient management practices in Arkansas, through a collaborative farmer-stakeholder partnership program.

Results to date indicate that Arkansas farmers are helping to keep sediment and nutrient losses lower than what many had previously perceived.

The Arkansas Discovery Farm (ADF) Program is a statewide collaborative effort to monitor and demonstrate the on-farm effectiveness of conservation practices (CPs) to minimize nutrient runoff (Sharpley et al., 2015). A similar effort is in various stages of operation in Minnesota, South Dakota, and Wisconsin and all are charged to some extent to develop nutrient loss reduction strategies to mitigate local and regional water quality concerns.

Nutrient enrichment remains a major impairment to the designated uses of fresh and coastal waters of the U.S. (Dale et al., 2010; Jarvie et al., 2015; Rebich et al., 2011). While there are many sources of nutrients, the contribution of agriculture, in particular intensive livestock and crop production, has received increased attention to reduce nutrient losses. This attention has been fueled by recent modeling efforts and surveys that have suggested that agriculture remains a major contributor of nutrients to surface waters and their impairment. For instance, a recent model estimates that up to 85% of the N and P entering the Gulf of Mexico originates from agriculture, with Arkansas estimated to be the fourth largest contributing state (Alexander et al., 2008). These estimates are based on large-scale modeling within the Mississippi River Basin. Few farm- or field-scale studies of P and N loss from agricultural production systems have been done in the Basin.

One of the first tasks to determine the need for any additional conservation or nutrient management practice changes on a farm is to determine whether nutrient runoff is an issue or not. There are 12 ADFs operating across Arkansas (**Figure 1**), to measure sediment and nutrient loss from representative fields and farms. Uniquely, the Program involves agriculture producers, scientists, and natural resource managers in work to jointly identify on-farm conservation issues and potential solutions. The Discovery Farm approach to agricultural sustainability challenges is based on the following four cornerstones: 1) sound science, 2) unbiased research, 3) stakeholder driven transparency, and 4) strong partnerships. In Arkansas, the CPs evaluated include managing the rate, timing and placement of fertilizer, reducing tillage, use of cover crops, buffer strips, and water harvesting, along with other practices.

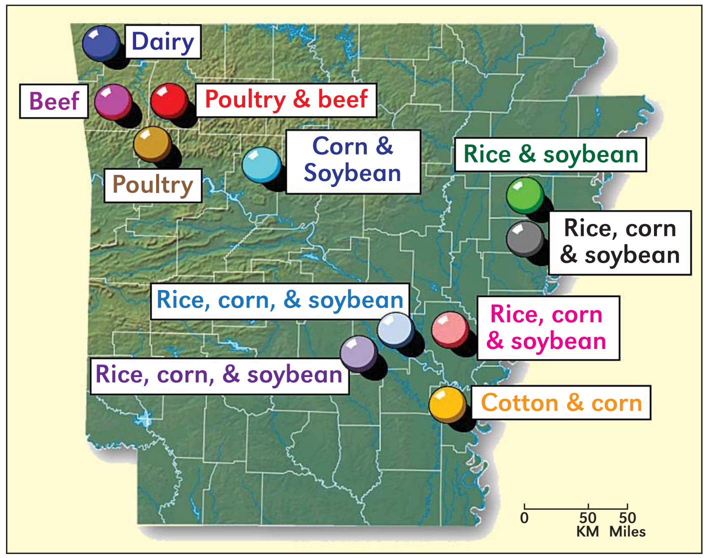

Figure 1. Location of Discovery Farms in Arkansas.

How the Program Works

Only farm operations reflective of typical crop, livestock, and poultry systems are used. Most often, we equip three to four sites (fields) with monitoring stations, which allow us field by field comparisons or comparisons of two to three scenarios, with a control site. At each site, state-of-the-art equipment is installed to monitor runoff, nutrient and sediment transport, and irrigation water-use efficiency. Equipment to monitor flow can vary from site to site depending on field size and presence or absence of natural drainage outlets.

Generally, auto-samplers are programmed to collect 100 ml samples integrated across various stages of the flow hydrograph—with up to a total of 10 L during each runoff event. Each composite flow-weighted sample is collected and analyzed following U.S. Environmental Protection Agency standards for suspended solids, N (as nitrate-N, ammonium-N, and total N), and P (as dissolved and total P) within 24 hours of collection.

For irrigated row crops, irrigation inflow is measured with in-pipe flow meters to determine application rates and cumulative irrigation volume. In some situations, evapotranspiration (ET) gauges are utilized to estimate daily ET losses. Soil moisture sensors are utilized to estimate change in soil water volume. Monitoring stations at the drainage outlet of the field

Abbreviations and notes: N = nitrogen; P = phosphorus.

Flumes to measure discharge from fields near Wedington, Arkansas (left) and Dumas, Arkansas (right).

allow for the determination of "tail water" losses from irrigation and/or rainfall.

What has been Learned to Date?

Nutrient runoff from pastures fertilized with mineral as well as manure nutrients can be reduced three-fold by simply maintaining a good stand of grass cover, avoiding concentrated water flow, and avoiding nutrient applications to wet soils when heavy rains are forecast in the next 3 to 5 days. For instance, on one poultry/beef grazing operation, the farmer set aside an ungrazed, unfertilized pasture as a grassed waterway to capture and trap nutrients running off from around the broiler house area. Averaged across 2013 to 2015, annual runoff flow, P, and N decreased 88, 50, and 29% respectively, over the 686 ft. reach of pasture (**Table 1**).

Table 1. Mean annual runoff flow, and total P and N loss from poultry houses decreases after passing through a 686 ft. grassed waterway (2013 to 2016), Arkansas.

Location	Flow gal/A/year	Total P	Total N
		------ lb/A/year ------	
In flow	693,720	0.4	1.4
Out flow	80,540	0.2	0.4

One common finding has resonated with our row crop farms: only a small proportion of the N and P applied as fertilizer each year is lost in runoff from no-till corn, cotton, rice, and soybeans (**Table 2**). Typically, these losses are less than 5% of that applied. Losses are decreased further where winter cover crops were planted to protect the soil surface and the applied nutrients and crop protectants from runoff and erosive forces.

Because of dramatic declines in aquifer levels over the last decade in the Delta region of Arkansas, these areas are now designated by the state as critical groundwater zones. As a result, more farmers are turning to land-levelling and water harvesting to enhance water use efficiency and to ensure adequate irrigation water supplies through the growing season. On these farms, nutrient loss is minimal as farmers are doing all they can to retain any rainwater or runoff on their farm in reservoirs or retention ponds. One Discovery Farmer started using the University of Arkansas Cooperative Extension Service irrigation scheduling program – PHAUCET (Pipe Hole and Universal Crown Evaluation Tool), and was able to appreciably increase irrigation water use efficiency by reducing irrigation runoff (**Table 3**). Less water leaving the farm has also resulted in less nutrient runoff loss.

Table 2. Mean annual N and P loss in runoff is a small proportion of that added in fertilizer (2014 to 2015), Arkansas.

Crop system	Location	Applied	Loss	Loss expressed as portion of fertilizer nutrient added
		- - lb/A/year - -		%
		Nitrogen		
Pasture	Elkins	150	0.3	0.2
Corn	Atkins	120	1.7	1.4
Cotton	Dumas	110	6.1	5.5
Corn	Dumas	268	4.4	1.6
		Phosphorus		
Pasture	Elkins	50	0.1	0.2
Corn	Atkins	22	0.5	2.3
Cotton	Dumas	42	1.9	4.5
Corn	Dumas	41	0.9	2.2

Table 3. Irrigation water volume, runoff and use-efficiency for corn and cotton production in southeast Arkansas for 2015.

Crop	Irrigation events	Irrigation volume	Runoff volume	Irrigation efficiency[1]
		--- acre-inches ---		%
Corn	6	2.23	0.31	85
Cotton	4	2.44	0.22	91

[1] Expressed as portion of irrigation water retained in the field.


Automated sampler collects water during runoff at Atkins, Arkansas (left) and in-line water flow meter for irrigation water input (right), at Dumas, Arkansas.

Summary

Implementation of standard water quality monitoring methods on private working farms across the state has started to document the true impacts of Arkansas agriculture on surface water quality and efficiency of current cropping systems and the implemented conservation practices. As this runoff monitoring is being conducted on private property, the results are having greater impact and resonate more with the farming community than work conducted on University property. In fact, we are already seeing a sense of farmer ownership of the Discovery Farm Program to the extent that cooperating farmers are requesting runoff data from the ADF Program in order to present their results at farm meetings. In some cases, neighboring farmers are voluntarily implementing additional conservation practices to further reduce nutrient runoff after seeing the ADF results. Most importantly, the Discovery Farm Program is empowering farmers to proactively address environmental concerns. More information on the ADF Program can be found on it's website at http://discoveryfarms.uark.edu/. BC

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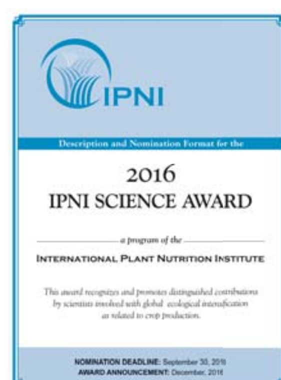
IPNI Science Award – Nominations Are Due September 30, 2016

Each year, the International Plant Nutrition Institute (IPNI) offers its IPNI Science Award to recognize and promote distinguished contributions by scientists. The Award is intended to recognize outstanding achievements in research, extension or education; with focus on efficient management of plant nutrients and their positive interaction in fully integrated crop production that enhances yield potential. Such systems improve net returns, lower unit costs of production, and maintain or improve environmental quality.

The IPNI Science Award requires that a nomination form (no self-nominations) and supporting letters be received at IPNI Headquarters by September 30, 2016. Announcement of Award recipient will be in December, 2016. An individual Award nomination package will be retained and considered for two additional years (for a total of three years). There is no need to resubmit a nomination during that three-year period unless a significant change has occurred.

All details and nomination forms for the 2016 IPNI Science Award are available from the IPNI Awards website http://www.ipni.net/awards.



IPNI

Description and Nomination Format for the

2016

IPNI SCIENCE AWARD

a program of the

INTERNATIONAL PLANT NUTRITION INSTITUTE

This award recognizes and promotes distinguished contributions by scientists involved with global ecological intensification as related to crop production.

NOMINATION DEADLINE: September 30, 2016

AWARD ANNOUNCEMENT: December, 2016

In-Season Decision Support Tools for Estimating Sidedress Nitrogen Rates for Corn

By Bee Khim Chim, Paul Davis, Tyler Black, and Wade Thomason

Four different in-season N rate decision support tools were equally effective in generating yield, but differences in N use efficiency were detected.

The Virginia Corn Algorithm (VCA) approach appeared best able to prescribe best fit, sidedress N rates under varying preplant N supply options.

The ability to provide a seasonally adjusted sidedress N rate reduces the emphasis on preplant N rates to allow a better match with crop demand and improved N use efficiency.

Nitrogen is frequently the most limiting factor in cereal crop production and 115 million metric t of nitrogenous fertilizers are applied annually to support crop production (FAO, 2015). Fertilizer nitrogen use efficiency (NUE), is estimated to be 33% and 42% for global cereal and U.S. corn production, respectively (Raun and Johnson, 1999). Improving N fertilizer management necessitates the application of the right amount of N using the right source at the right timing, in the right place (Bruulsema et al., 2009). While determining the best approach for any of these factors is complicated, rate is perhaps the most difficult due to the complexities of the N cycle.

There are many tools to assist in the determination of optimum corn sidedress N rate; however, those that can be used in real time do not require extensive sampling and should be inexpensive. Experiments that evaluated four strategies for in-season rate determination were conducted in New Kent, Virginia Beach, Lottsburg, and Blacksburg, Virginia from 2012-14. Experiments had 16 treatments using four different pre-plant N rates (0, 40, 80, 120 lb/A) applied as urea (46% N) that were combined with sidedress rates prescribed by: 1) the Virginia Corn Algorithm (VCA), 2) the Maize-N® simulation model, 3) the Nutrient Expert® for Hybrid Maize (NE-Maize) simulation model, and 4) the standard yield-goal based rate. Fertilizer source for all sidedress applications was liquid urea ammonium nitrate-UAN (30% N). An indicator used to compare nutrient use efficiency in crop production called Partial Factor Productivity (PFP) was calculated by dividing the grain mass (lb/A) by the total N applied (lb/A).

Decision Support Tools

The standard rate was determined based on guidelines in the Virginia Nutrient Management Standards and Criteria (Virginia DCR, 2014). Yield estimates were based on the soil productivity assigned to the dominant soil series for each site. Nitrogen rate recommendations are based on prescribing 1 lb N/bu of expected grain yield and subtracting the appropriate amount of pre-plant fertilizer applied, if any.

The Maize-N simulation model is a subunit of the Hybrid-Maize® simulation model. It relies on a database of rate-to-response studies paired with historic climate data to develop N rate estimates. The program predicts corn yield potential, estimates recovery efficiency of applied N fertilizers, and estimates the economically optimal N rate (EONR) of fertilizer for the current corn crop (Yang et al., 2006). The Hybrid-Maize model was used because the user may edit almost all parameters relevant to model output allowing for local calibration, it is relatively simple to use, and it has been validated in multiple environments.

Abbreviations and notes: N = nitrogen; NDVI = normalized difference vegetation index.

Sidedress application of liquid urea ammonium nitrate (UAN) application across plots receiving different amounts of preplant N.

The NE-Maize model is a nutrient decision support software that uses the principles of site-specific nutrient management (SSNM) and allows development of field-specific fertilizer recommendations. Nutrient Expert incorporates the most important factors affecting nutrient management recommendations using a systematic approach. The algorithm for calculating fertilizer requirements in NE-Maize is determined from on-farm trial data using SSNM guidelines (IPNI, 2016).

The VCA utilizes a deterministic approach to estimate N needs, based on the previous rate to response studies where NDVI data were collected at sidedress time, in addition to yield response. Rate estimates are determined from the difference in NDVI between the 120 lb N/A and 0 N reference plots at sidedressing time divided by the days from seeding to estimate the current plant N uptake and the potential N response index (Thomason, 2011).

Table 1. Corn grain yield and realistic expected yield at each experimental location, 2012-2014.

Year	Site	Grain yield, bu/A	Realistic expected yield, bu/A†
2012	New Kent	116	150
2013	New Kent	163	180
	Virginia Beach	164	170
	Blacksburg	92	150
2014	New Kent	184	180
	Lottsburg	147	150
	Blacksburg	123	150

† Virginia Department of Conservation and Recreation, 2014.

Grain Yield and Sidedress N Rate

Average grain yield over all locations was 141 bu/A, which is slightly greater than the statewide average yield in Virginia (134 bu/A) over the same period of time. Yields ranged from 92 to 184 bu/A at the various sites (**Table 1**) mostly due to variation in rainfall. Grain yields were similar among in-season N recommendation systems over the various preplant rates at all sites. This is likely because all approaches provided N at agronomically appropriate or higher rates.

Sidedress N rate recommendations were affected by recommendation system, pre-plant N rates, and the interaction at all locations (**Table 2**). All systems recommended decreasing sidedress rates with increasing preplant N application rates, however, not all systems accounted for the preplant application in the same manner as the decrezase was not uniform. The lowest recommended rates were prescribed by the VCA and the highest by NE-Maize (**Table 2**). Models developed in other ecoregions may not adequately assess the severity of acute moisture stress that often occurs in these sandy soils with low water holding capacity, resulting in an overestimate of N need. In contrast with the other systems, utilization of in-season canopy sensors with the VCA may allow more accurate estimatation of temporal N need.

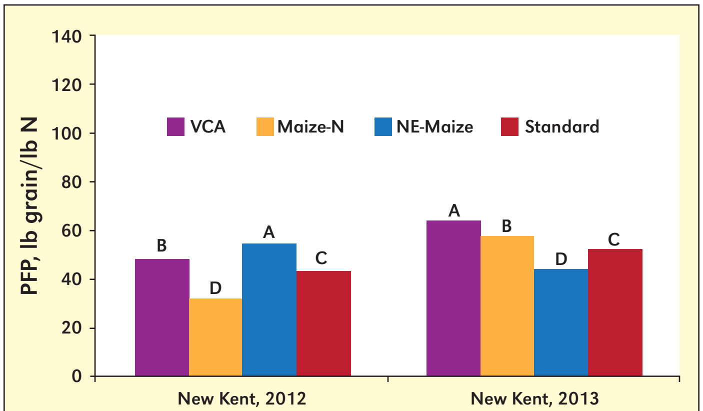


Figure 1. Partial factor productivity (PFP) of N for four in-season N sidedress recommendations systems at New Kent, 2012 and 2013. Means for a given location labeled with the same letter are not significantly different at $p = 0.05$. VCA = Virginia Corn Algorithm; Maize-N = Subunit of the Hybrid-Maize® simulation model; NE-Maize = Nutrient Expert® for Hybrid Maize simulation model; Standard = yield-goal based rate.

Table 2. Preplant N rates and sidedress N rates prescribed by four in-season strategies, 2012-2014.

Year	Location	Preplant N rate	VCA	Maize-N	NE-Maize	Standard
		------------- lb/A -------------				
2012	New Kent	0	122	198	116	150
		40	70	155	82	110
		80	55	120	48	70
		120	40	82	16	30
2013	New Kent	0	130	150	200	180
		40	100	110	170	140
		80	70	70	130	100
		120	30	30	100	60
2013	Virginia Beach	0	100	150	180	170
		40	60	100	150	130
		80	30	70	120	90
		120	0	30	80	50
2013	Blacksburg	0	100	70	170	150
		40	70	30	129	110
		80	30	0	89	70
		120	0	0	49	30
2014	New Kent	0	90	170	150	180
		40	50	100	90	140
		80	0	40	70	100
		120	0	0	30	60
2014	Lottsburg	0	120	210	170	150
		40	100	150	130	110
		80	50	80	90	70
		120	15	20	50	30
2014	Blacksburg	0	100	120	170	150
		40	60	90	130	110
		80	20	70	90	70
		120	0	50	50	30
Source		------------- Pr > f -------------				
System		***	***	***	***	***
Preplant N		***	***	***	***	***
System*PreN		***	***	***	***	***

***significant at $p = 0.01$. VCA = Virginia Corn Algorithm; Maize-N = Subunit of the Hybrid-Maize® simulation model; NE-Maize = Nutrient Expert® for Hybrid Maize simulation model; Standard = standard yield-goal based rate.

Partial Factor Productivity of Nitrogen

The effect of sidedress recommendation system on PFP of N was only significant at New Kent in 2012 and 2013. At New Kent in 2012, the highest PFP (averaged over N rates) occurred with the NE-Maize (55 lb grain/lb N applied), while in 2013 the VCA had the greatest PFP (64 lb grain/lb N) (**Figure 1**). Rainfall totals and grain yield were lower in 2012 and the NE-Maize model more accurately predicted N need under these conditions.

Sidedress N rate recommendations were affected by preplant N at all other sites. There were significant differences

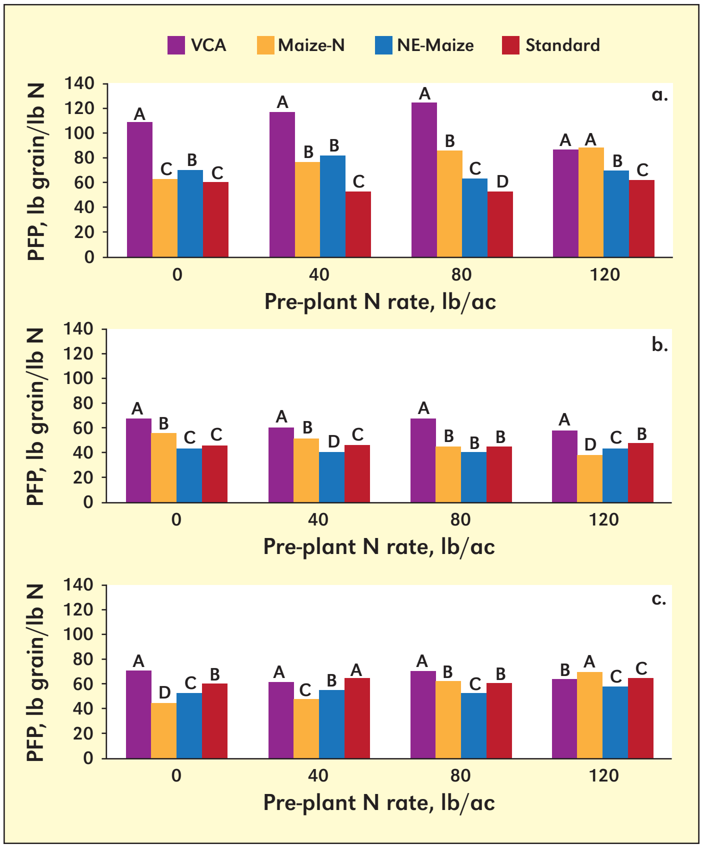


Figure 2. Partial factor productivity (PFP) of N for four in-season N sidedress recommendations systems at four preplant N rates at New Kent (a), Blacksburg (b), and Lottsburg (c), 2014. Columns labeled with the same letter within a preplant rate are not significantly different at $p = 0.05$. VCA = Virginia Corn Algorithm; Maize-N = Subunit of the Hybrid-Maize® simulation model; NE-Maize = Nutrient Expert® for Hybrid Maize simulation model; Standard = yield-goal based rate.

in PFP among systems at Blacksburg in 2013 when 0, 40, and 80 lb N/A was applied but not 120 lb N/A. The highest PFP at Blacksburg and Virginia Beach in 2013 was associated with the rates prescribed by Maize-N and the VCA, respectively. Similar to what happened in New Kent in 2012, yields in Blacksburg in 2013 were limited by lack of late-season rainfall, but the Blacksburg site was a silt loam soil and the Maize-N model was likely more capable of estimating N need under these combined conditions.

In 2014 at New Kent, the highest PFP was observed with use of the VCA at 0, 40, and 80 lb/A preplant N rates and was equal to Maize-N at the 120 lb/A preplant rate (**Figure 2a**). At Blacksburg, the greatest PFP was similarly associated with use of the VCA, but overall, PFP for the VCA at this site was less (64 lb grain/lb N) than at New Kent (**Figure 2b**). No approach consistently produced the highest PFP at Lottsburg in 2014 (**Figure 2c**), but PFP was highest at 59 lb grain/lb N for the VCA, overall. While the performance of the various sidedress N recommendations varied among sites, PFP for the VCA approach was greatest in four of seven locations and averaged 68 lb grain/lb N.

Corn plot harvest near New Kent, Virginia.

Summary

Yields were similar among systems at all sites, indicating that all approaches provided adequate N to support the measured yield. There were significant differences in sidedress rates prescribed among systems. At four of seven locations, sidedress rates prescribed by the VCA were significantly less than the other systems, especially at lower preplant N rates. Overall, PFP declined with increasing preplant N rate, regardless of in-season N recommendation system. This is not surprising since in-season applications typically better match N supply with crop demand, resulting in increased NUE. The greatest PFP usually resulted from implementing the in-season N rate recommendations generated from the VCA approach (four of seven locations), though the Maize-N model also shows promise in this environment. Growers should consider new techniques that utilize current season data, such as the VCA, to refine sidedress N rates. BC

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Impact of Soil Applied Potassium on Cotton Yield and Profitability

By Mike Stewart and Gaylor D. Morgan

The frequency and severity of K deficiency symptoms is increasing on some highly productive cotton-producing soils in Texas.

The effects of K fertilizer rate and placement were investigated to determine their impact on cotton yield, fiber quality parameters, and profitability.

Where response to K was observed, band outperformed broadcast applications, with significant improvement in yield and return on investment.

Texas produces more cotton than any other state in the U.S. Over the three most recent years of production (2013-15), Texas has produced 40% of total U.S. cotton (USDA-NASS, 2016). Most of this production comes from the High Plains of Texas—the largest contiguous cotton-producing region in the world. But other areas within the state such as the Trans-Pecos, Rolling Plains, Rio Grande Valley, Blacklands, and Coastal Prairie regions also produce significant amounts of cotton (**Figure 1**). **Table 1** illustrates the economic importance of Texas cotton production relative to other common crops.

A major factor affecting both cotton yield and quality is the availability of adequate and balanced nutrition. Potassium is an especially important nutrient in cotton production. It reduces the incidence and severity of wilt diseases, increases water use efficiency, and affects fiber properties like length, strength, and micronaire. It is important in maintaining sufficient water pressure within the boll for fiber elongation, and for this reason bolls are a major sink for K. Cotton takes up about 60 lbs of K_2O per bale of lint produced. The need for K increases dramatically during early boll set, and about 70% of uptake occurs after first bloom. Potassium deficiency may be expressed as a full season deficiency, or it may not appear until late season since this is the period of greatest demand. A shortage of K compromises lint yield and quality, and results in plants that are more susceptible to drought stress and diseases.

Soil K has mostly been considered adequate in cotton-producing regions of Texas; however, the frequency and severity of K deficiency symptoms on the highly productive clay soils in the Central Blacklands and Gulf Coast regions have increased in recent years. This increased occurrence of K deficiency in cotton, and other row crops, is a major concern for producers, agribusiness, and scientists. This study was undertaken to investigate the effect of K fertilizer rate and placement on cotton yield, fiber quality parameters, and profitability in the the region's fine textured soils.

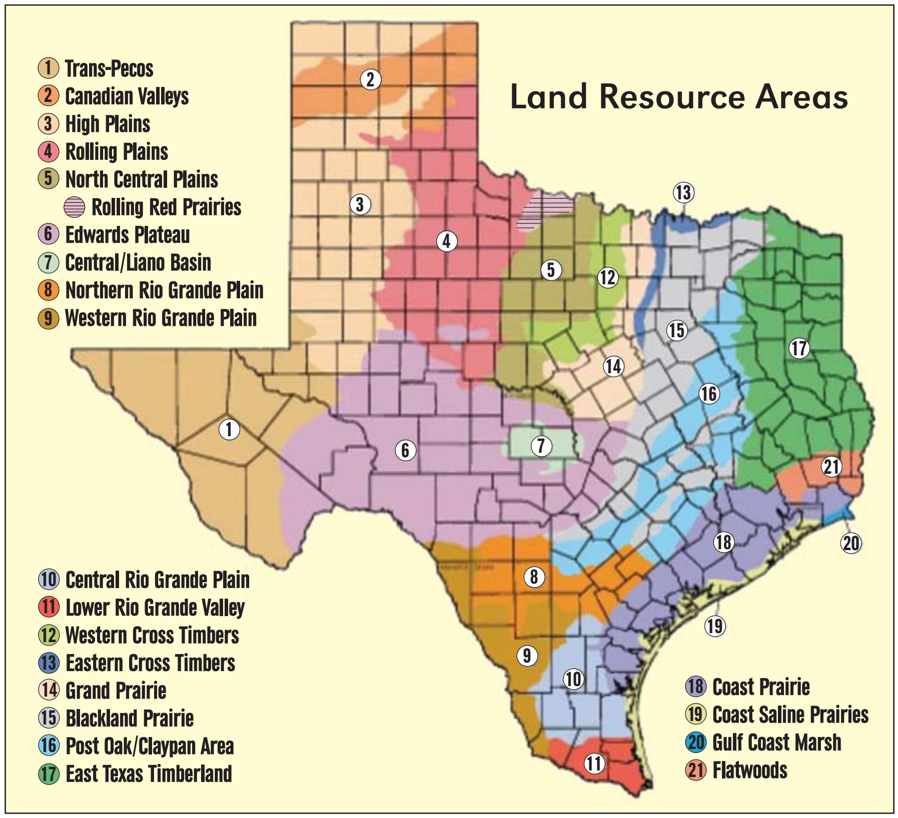


Figure 1. Land resource areas of Texas. © 2010 Texas Almanac graphic.
Source: Natural Resources Conservation Service of the U.S. Department of Agriculture.

Table 1. Total cash receipts (farm gate value), contribution to GDP, and economic output for selected agricultural commodities in Texas, 2014.

	Total cash receipts, $	Total contribution to GDP, $	Economic output, $
Cotton	2,169,527,000	1,954,526,900	5,118,001,000
Corn	1,308,269,000	1,082,200,100	2,814,399,300
Grain sorghum	541,265,000	447,734,400	1,164,390,400
Wheat	436,840,000	361,354,000	939,747,200
Livestock[1]	14,248,322,600	10,707,650,200	34,886,300,500
Forages	1,790,363,700	1,681,688,600	3,924,539,800
Total	20,494,587,300	16,235,154,200	48,847,378,200

[1]Livestock category includes beef cattle and calves, dairy, sheep, and goats, but does not include swine or poultry.
USDA-ERS, 2014. From Hanselka et al., 2016.

Abbreviations and notes: K = potassium; KCl = potassium chloride; S = sulfur; ppm = parts per million. IPNI Project TX-56

Table 2. Cotton study sites, soil K levels (0-6 in.), K recommendation, and cotton variety.

Year and Location	Soil series	Soil test K, ppm	*Recommended K, lb K_2O/A	Cotton variety
2012				
Williamson	Burleson clay	60	60	DP 0935 B2RF
2013				
Williamson	Burleson clay	65	60	Phytogen 499 WRF
Wharton	Lake Charles clay	150	0	DP 0935 B2RF
2014				
Williamson	Burleson clay	105	20	Phytogen 499 WRF
Wharton	Lake Charles clay	180	0	ST 6448 GLB2

*Recommendation from Texas A&M Univ. lab for 2 bale/A lint yield (Texas A&M, 2016).

The study was conducted on a limited scale in 2012 with only one site in the Blacklands region (Williamson Co.) on the Stiles Farm. Results from 2012 were of such interest that the study was subsequently expanded in 2013 and 2014 to include additional farmer field sites in Williamson Co., Hill Co. (Blacklands), and Wharton Co. (Gulf Coast Region). Locations for 2013 and 2014 in Blacklands (Williamson and Hill Co.) and Gulf Coast (Wharton Co.) regions were chosen based on past foliar K deficiency observations. **Table 2** shows soil series, K soil test level (0 to 6 in.), university recommended K fertilizer input (based on a 2 bale/A yield goal), and cotton variety for the site years reported in this article. There were two site years in Williamson Co. and one in Hill Co. that are not reported here since they were not responsive to either rate or placement of K fertilizer. These sites were well above the K sufficiency level of 120 ppm (Texas A&M, 2016), ranging from about 230 to 400 ppm K. It should be noted that soil samples were collected to a depth of 4 ft., but only the 0 to 6 in. depth is reported in this paper.

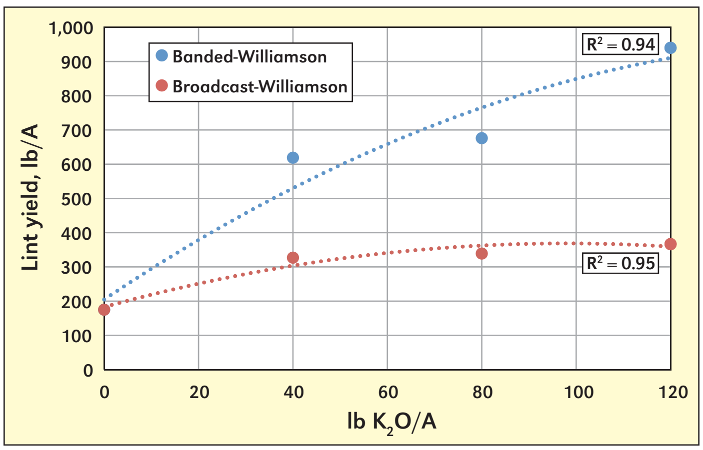


Figure 2. Lint yield response to K fertilizer and placement at the 2012 Blacklands site (Williamson Co.).

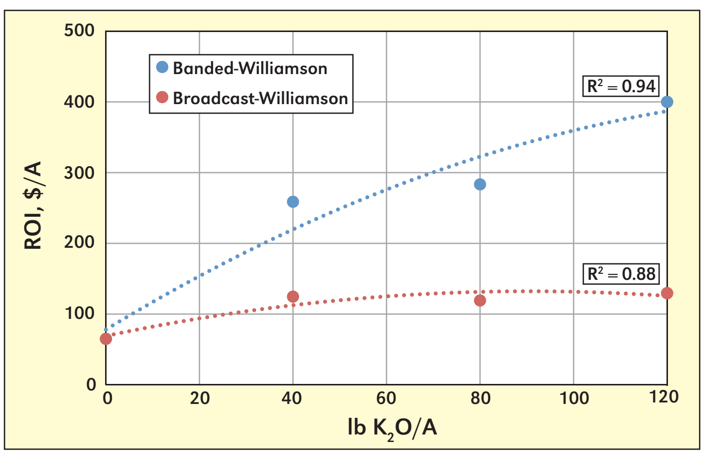


Figure 3. Return on investment (ROI) for 2012 treatments in the Blacklands (Williamson Co.). ROI was calculated by subtracting cost of K fertilizer from the gross lint income, which is affected by both lint yield and quality. Factors such as application and tillage costs, and value from seed were not used in this ROI calculation. Lint values were calculated using the 2013 Upland Cotton Loan Valuation Model from Cotton Inc. and 2013 cotton lint price.

Fertilizer K comparisons included both rate and placement. Potassium fertilizer was either banded to the side (4 in. to side of row and 6 in. deep, or 4x6) or broadcast incorporated prior to planting. Granular KCl (0-0-60) was used for the broadcast treatments, and fluid KCl (0-0-15) was used for the banded treatments. The same source (KCl) was used for both placement variables in order to avoid confounding with nutrients (e.g., S) that might have come with using other fluid K sources. All treatments were applied, and granular application incorporated, about two weeks before planting.

Treatments for the first year (2012) were more limited than subsequent years, with broadcast and banded rates of 0, 40, 80, and 120 lb K_2O/A. For 2013 and 2014 the broadcast incorporated treatment was applied at rates of 0, 40, 80, 120, and 160 lb K_2O/A, and the banded treatment was applied at 0, 20, 40, 80, 120, and 160 lb K_2O/A. The only difference in rates for the placement variable was the omission of 20 lb/A in the broadcast treatment.

Plant measurements during the season included height, total nodes, and nodes to first fruiting branch. After the growing season, plots were harvested, seed cotton weighed, and then ginned. After ginning, samples were sent to Cotton Inc. to determine fiber quality (i.e., fiber length, strength, micronaire, uniformity, and other characteristics).

Results

There was some variation in height and total nodes among the different K treatments, but the biggest visual difference was the presence of K deficiency symptoms in the leaves that received zero or low rates of K fertilizer (see Photo). Plots with higher rates of K did not exhibit deficiency symptoms.

Figure 2 shows lint yield results from 2012. Lint yield was generally increased by K fertilizer, with the banded treatments producing dramatically more lint than broadcast at all rates. **Figure 3** shows return on investment (ROI) for the 2012 treatments. The ROI takes into account the impact of K on both yield and lint quality. The ROI for banded treatments exceeded that for broadcast K, and ranged from about $260 to $400/A. The ROI for the 120 lb banded treatment exceeded that of the control by $335/A. As would be expected, these initial (2012)

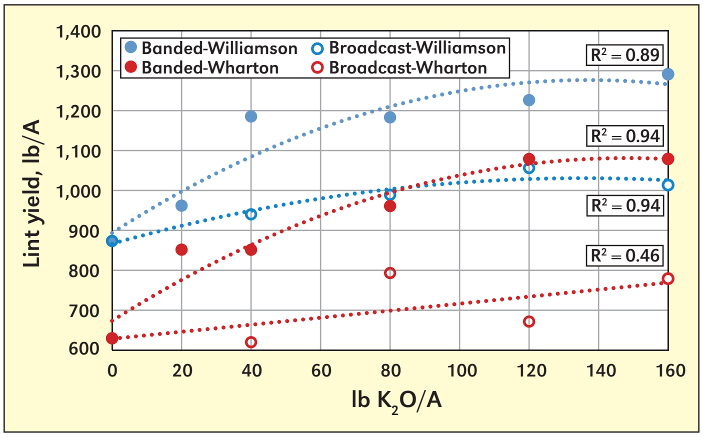


Figure 4. Lint yield for Blacklands (Williamson Co.) and Gulf Coast (Wharton Co.) region sites in 2013.

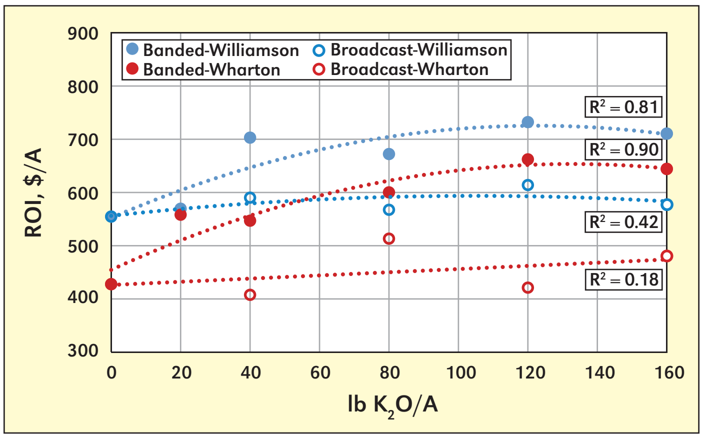
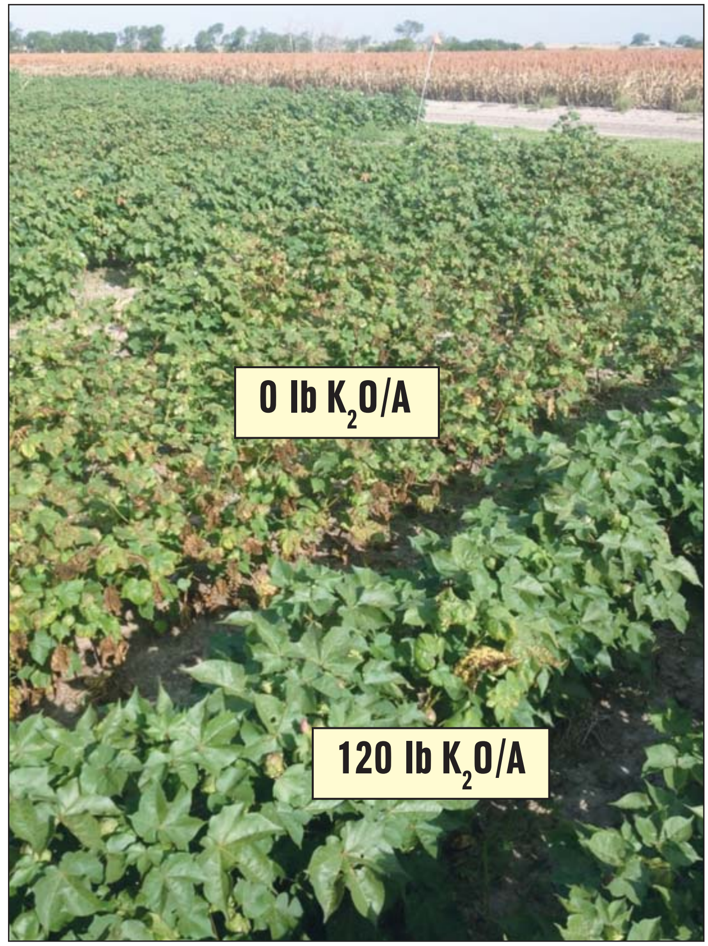


Figure 5. Return on investment (ROI) for 2013 treatments in the Blacklands (Williamson Co.) and Gulf Coast (Wharton Co.) region sites. ROI was calculated by subtracting cost of K fertilizer from the gross lint income, which is affected by lint yield and quality. Factors such as application and tillage costs, and value from seed were not used in this ROI calculation. Lint values were calculated using the 2014 Upland Cotton Loan Valuation Model from Cotton Inc. and 2014 cotton lint price.

results, particularly the impact of banded K, gained considerable attention and ultimately resulted in the expansion of this project to other sites in 2013 and 2014.

Figure 4 shows 2013 yield results for both the Blacklands (Williamson Co.) and Gulf Coast (Wharton Co.) region sites, while **Figure 5** shows the ROI for each of these sites in the same year. The Wharton Co. site did not show a significant response to any rate of broadcast K fertilizer; however, all rates of injected K showed a significant response over the control. The highest yields at this site (1,080 lb lint/A) were observed where 120 and 160 lb K_2O was banded, and were 450 lb—almost a bale—higher than the control (630 lb lint/A). According to ROI calculations the greatest return at the Wharton Co. site in 2013 was with the 120 lb K_2O banded treatment, where ROI was $662. These results are especially interesting considering that the soil test K level at the Wharton Co. site (150 ppm) was above the critical value of 120 ppm.

For the Williamson Co. site in 2013 only the 120 and 160 lb K_2O broadcast rates showed significant lint yield response



Effect of K fertilization on cotton K deficiency and late season foliar disease in the Texas Blacklands (2013). The 0 lb K_2O/A is in the middle of the image, and the 120 lb K_2O/A was applied in a 4x6 band.

when compared to the control; however, all of the banded treatments, except the 20 lb rate, showed significant lint yield response (**Figure 3**), but were not significantly different from each other. So the 40 lb banded treatment optimized both yield and ROI at this site in 2013, with a yield increase of 36% (311 lb lint) over the control and an increase in ROI over the control of $148 (i.e., $555 to $703). The response to K fertilizer at this site was not unexpected since the soil K level (65 ppm) was below the critical level (120 ppm).

Yields were substantially higher at the Wharton Co. site in 2014 than in 2013, conversely, yields at the Williamson Co. site were lower in 2014 than in 2013. Interestingly, there was no effect from K fertilizer treatments at either site in 2014.

Discussion

Cotton response to K fertilizer was clear and dramatic at the Warton and Williamson Co. sites reported here in 2013. But, there was essentially no response in 2014 at these sites. The lack of response cannot be definitively explained. But, the most likely explanation involves rainfall distribution during the season. In 2014 at Williamson Co., soil moisture was not limited early in the season; however, excessive heat and moisture stress occurred during boll fill and resulted in poor fruit set and very low yields across all treatments. At Wharton Co., moisture was not limited and a late maturity variety (ST 6448 GLB2) was grown in the trial. Late maturing varieties create less intense demand on nutrient uptake, including K.

Where cotton was responsive to K fertilizer there was a distinct advantage to band application over broadcast, both for yield and ROI. The reason for the better performance of banding is not completely understood. It has been speculated that since the soils in this study are fine textured there could be some K fixation occurring wherein high charge clay minerals (e.g., vermiculite, highly charged smectite) "fix" broadcast K fertilizer to a greater extent than banded K fertilizer. Detailed mineralogical analysis of these soils is planned to determine whether fixation may be a factor.

Concluding Thoughts

This study illustrates the importance of ongoing efforts to continue to further our understanding of K nutrition and soil interactions. More specifically, the findings here support the need for efforts that explore the new frontiers in K science. In 2015, IPNI tasked an international group of accomplished scientists to identify critical concepts that were missing or were inadequately characterized in existing soil K assessments or K recommendations. In the summary paper produced from this group (IPNI, 2015) the authors state *"Practitioners have often not been able to explain why soil-test K varies across the landscape or over time in response to management practices. Additionally, definitive calibrations of K soil tests to crop responses have not been achievable in some areas"*—a statement befitting the study reported here. Finally, the findings from this study have resulted in the formation of a larger and similar project that is being conducted across 12 cotton-producing states. BC

Acknowledgement

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Frontiers of Potassium Science – Now Accepting Short Abstracts for Papers

IPNI is pleased to invite you to participate in this international conference being held in Rome, Italy on January 25-27, 2017.

Organizers have designed the conference as a forum to exchange information on how to improve potassium plant nutrition and soil management to better the health of soils, plants, animals, and humans.

The 4R Nutrient Stewardship framework is integrated into the conference structure to keep the discussions anchored to the information needs of farmers and those who provide nutrient management guidance.

The conference is now inviting short abstracts for paper submissions. The short abstract submission deadline is September 1, 2016.

Submissions addressing the list of example questions below (more complete list available at http://KFrontiers.org) will be given priority and will be considered for inclusion in a special peer-reviewed publication following the conference.

Potassium in Sustainable Intensification of Cropping Systems

How do potassium inputs and outputs compare for different cropping systems and geopolitical boundaries?

4R Source: Improving decisions about the source of potassium to apply

How does the source of potassium fertilizer affect its proper placement in the soil?

4R Rate: Improving the accuracy of potassium rate recommendations

Why and to what extent do various crops differ in their recovery efficiency of potassium?

4R Time: Improving decisions about when to apply potassium

What are the genetic effects on potassium accumulation rates, partitioning, and plant metabolism?

4R Place: Improving potassium placement decisions

What plant characteristics (rhizosphere biology and chemistry, root architecture, etc.) most influence potassium placement decisions?

Connecting Frontier Science to Frontier Practice

How do we increase the impact of scientific findings on soil and crop management of potassium in the field?

Please visit http://KFrontiers.org to obtain all details on submitting your short abstract and to sign up for updates about the conference.

We look forward to seeing you in Rome!

Nutrient Mining: Addressing the Challenges to Soil Resources and Food Security

By Kaushik Majumdar, Saroj Kumar Sanyal, Sudarshan Kumar Dutta, T. Satyanarayana, and V.K. Singh. 2016. *In* U. Singh et al. (eds). Biofortification of Food Crops. Springer. pp. 177-198.

The challenges facing Indian agriculture in meeting the future demand for food are summarized in a recent book chapter by several IPNI scientists and academic partners.

The current Indian population of 1.2 billion is expected to rise to 1.4 billion by 2025 and the country will need to produce more than 300 million tonnes (M t) of food grains to ensure food security. Meeting this additional food demand will be primarily accomplished through increasing the intensity of agricultural production, including improved crop genetics, enhanced nutrient management, and improved agronomic management.

Total annual fertilizer consumption in India increased from 0.07 M t in the early 1950's to 28 M t in 2011. Experts predict further increased demand for fertilizer through the next decade, but this additional nutrient application must be done with appropriate stewardship practices.

Transporting crop straw from the field, Tamil Nadu, India.

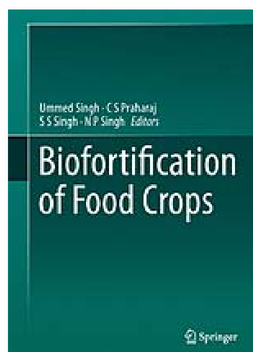
Native soil fertility (or indigenous nutrient-supplying capacity) is most commonly measured by soil testing, but plant-based approaches are also used (yield or tissue concentrations). The soil nutrient supply has been declining in many parts of the county, a trend that must be reversed if crop production goals are to be met.

The nutrient balance (difference between nutrient inputs and outputs) is a key indicator of the need for additional nutrient application. The largest contributor to nutrient mining is plant removal, but other processes can also lead to loss of nutrients from the soil (leaching, gaseous loss, erosion, etc.). Farmers need continued education for getting the maximum amount of their applied nutrients into their crops to avoid undesired losses. Indian farmers are also increasingly aware that soil carbon is a parameter that has an important role in mitigating global warming and maintaining soil tilth.

Recent estimates of nutrient mining from Indian agricultural soils indicate that nutrient removal far exceeds the combined nutrient additions of organic manures and fertilizers. Although a part of this nutrient deficit is met through biological processes such as N_2 fixation, there is still a national nutrient deficit of at least 8 to 10 M t N-P_2O_5-K_2O/yr.

In India, the annual N balance (nutrient additions/crop removal) is positive (+3.2 M t). The national P balance is negative (0.2 M t P_2O_5), especially in the western part of the country. The K balance is negative in every region of the country (-9.7 M t K_2O), especially in the west. Additions of K through manuring, residue recycling, and current low rates of fertilizer input are not nearly sufficient to match K removal by crops.

The continued removal of nutrients during crop harvest



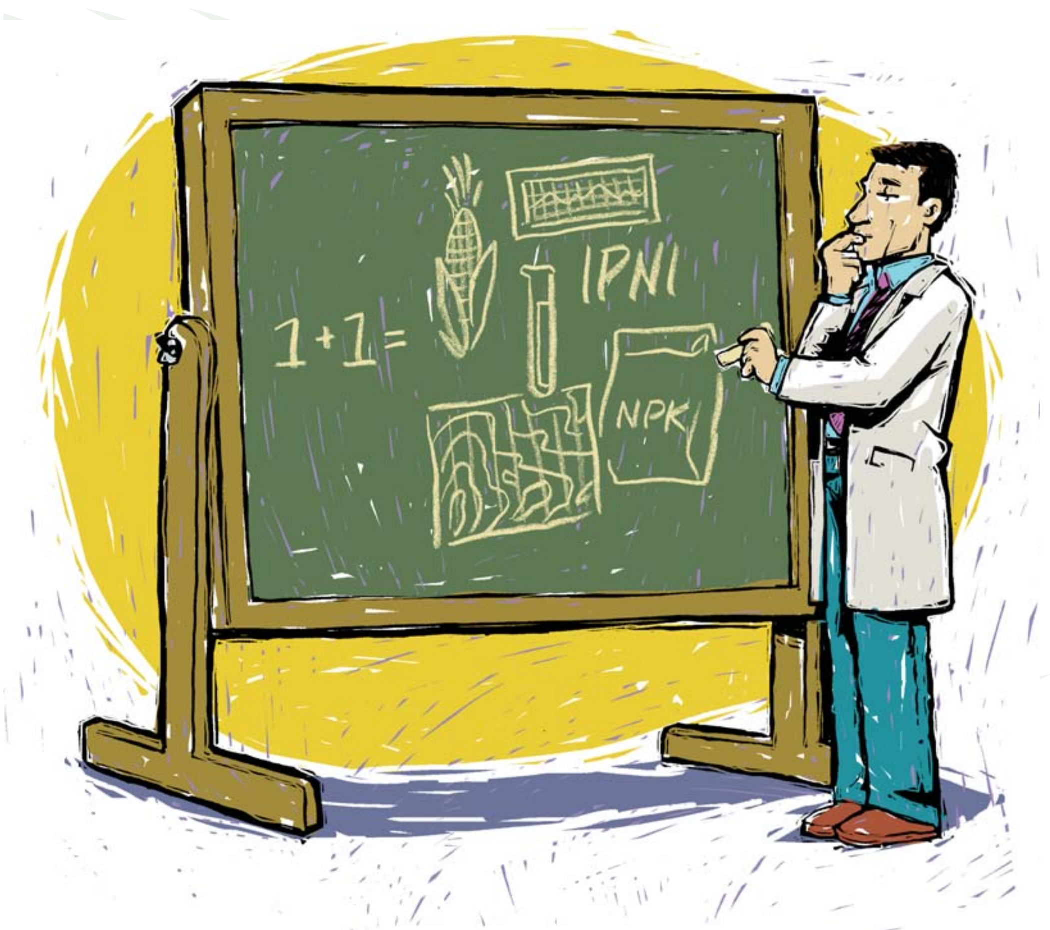
in the region has resulted in multiple nutrient deficiencies and harmful depletion of valuable soil nutrient reserves. Unfortunately, the current gap between nutrient use and crop removal is expected to widen as cropping intensity grows. In addition to using more fertilizer, local farmers should be encouraged to partially recycle crop residues instead of entirely removing them from the field, and apply animal manures to cropland instead of diverting them fully for household use.

The application of N fertilizer tends to be preferred by farmers because of their relatively low cost per unit of nutrient, their widespread availability, and the quick and evident response of the plant. Phosphate and K use are low compared with N, and secondary and micronutrients are generally omitted. Without balanced crop nutrition to supply all of the needed nutrients, it will not be possible to meet the upcoming food production challenges.

The book chapter concludes with a reminder that replenishment of Indian agricultural soils must be done in accordance with the principles of 4R Nutrient Stewardship (The Right Source of nutrients, applied at the Right Rate, and the Right Time, and in the Right Place). There is an urgent need for science-based approaches to improve current nutrient management strategies. BC

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

When does 1 + 1 ≠ 2?



Higher level math teaches us that one plus one does not always equal two. As in math, we often see response to two nutrients applied together greater than the individual response of each separately. In other words, "X can be greater than the sum of its parts".

The same principle applies to strategic partners. IPNI is successful because of the strategic partners and collaborators we work with. We are a small organization with 32 scientists working across the globe. But in the last 25 years, we have supported almost 2,200 research projects related to nutrient management. We provide ideas and a little seed money and find willing partners to work with. Those 2,200 projects cost us over $13 million, but the total cost of the projects was more than 10 times that.

We leave the "hands-on" research to our academic colleagues and other partners, who have the expertise, the laboratories, and field equipment and we use our expertise in extending the results they generate, in translating and teaching the practical applications to the end-users. Our partners do the research and we tell their stories. It's a great partnership, with each partner contributing to their strengths.

The benefits of working together are extraordinary and greatly rewarding. Agriculture is the beneficiary. The sum of our contribution plus that of our partners is much greater than either of us alone.

When it comes to fertilizers and ag research … one plus one is a lot more than two.

Terry L. Roberts
President IPNI

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