BETTER CROPS
WITH PLANT FOOD

A Publication of the International Plant Nutrition Institute (IPNI)

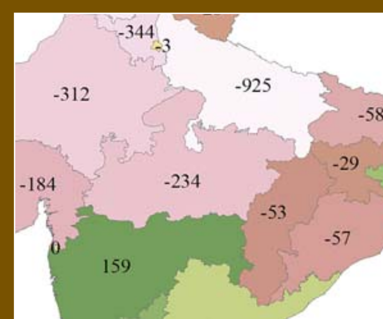
2014 Number 1

Photo Contest Results

In This Issue...

Identifying Win-Win N Management Systems

Mapping K Budgets Across India



Fine-tuning N Fertilizer BMPs for Potato

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Soil Acidity Evaluation and Management

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BETTER CROPS
WITH PLANT FOOD

Vol. XCVII (98) 2014, No. 1

Our cover: Rows of wheat seedlings breaking out of the soil.
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Circulation Manager: Wendy Hollifield
Design: Rob LeMaster

BETTER CROPS WITH PLANT FOOD (ISSN:0006-0089) is published quarterly by the International Plant Nutrition Institute (IPNI). Periodicals postage paid at Norcross, GA, and at additional mailing offices (USPS 012-713). Subscriptions free on request to qualified individuals; others $8.00 per year or $2.00 per issue. Address changes may be e-mailed to: whollifield@ipni.net

POSTMASTER: Send address changes to *Better Crops with Plant Food*, 3500 Parkway Lane, Suite 550, Norcross, GA 30092-2844. Phone (770) 447-0335; fax (770) 448-0439. Website: www.ipni.net.

Better Crops with Plant Food is registered in Canada Post.
Publications mail agreement No. 40035026
Return undeliverable Canadian addresses to:
PO Box 2600
Mississauga ON L4T 0A9 Canada

The Government of Saskatchewan helps make this publication possible through its resource tax funding. We thank them for their support of this important educational project.

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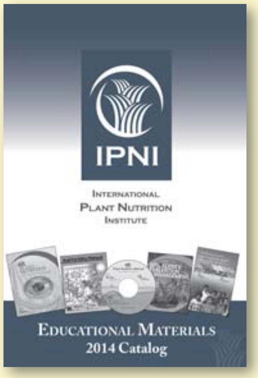
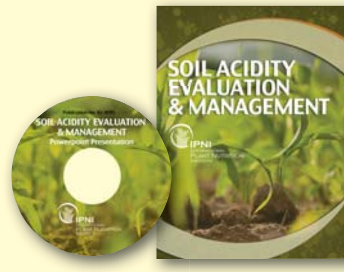
2014 IPNI Catalog of Publications Now Available

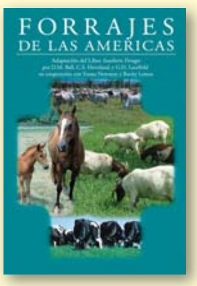


IPNI has released the 2014 edition of its catalog of publications, which provides the latest information on our growing list of booklets, books, manuals, learning tools and resources. This year's catalog includes a number of new additions and updates. Some of these changes are highlighted below. Requests for hardcopies of our catalog can be made by contacting our circulation department by e-mail at circulation@ipni.net or by phone (770-825-8084). A pdf version of the catalog can also be downloaded from our web site www.ipni.net …just look under our Publications section.

Booklets

Soil Acidity Evaluation & Management – An accompanying CD with PowerPoint slides plus speaker's notes is also available.





Books

Forrajes De Las Americas – Our Spanish translation of Southern Forages (4th Ed.) – a practitioner's reference of choice.

e-Books

4R Plant Nutrition Manual – Now for Kindle devices as well as iPad.

Soil Fertility Manual – Also brand new for Kindle devices.

Electronic Media

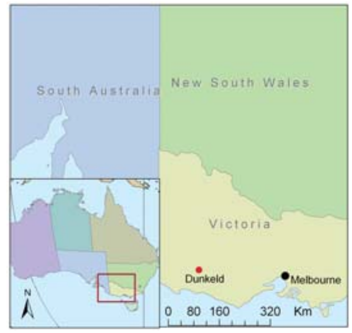
Crop Nutrient Image Collection on Flash Drive – Now a collection of nearly 570 images, it is fully functional in six languages (English, Spanish, French, Portuguese, Russian, and Chinese-Mandarin).

Publications from Our Regional Programs

The 2014 catalog once again highlights publications offered from our regional programs including our Spanish-based programs in Mexico, Central America, and South America), Portuguese publications originating from our Brazil program, Russian-language publications, and publications and resources available from our Southeast Asia program. BC

Nitrogen Management that Maximizes Margins Improves Sustainability of Wheat Cropping

By David Nash, Penny Riffkin, Rob Harris, Alan Blackburn, Cam Nicholson and Mark McDonald



Flexible wheat cropping systems that maximize crop potential with minimal N application at sowing, were found to maximize both economic and environmental performance in southeastern Australia. A range of management combinations were used to estimate the impact of different combinations of initial soil N status and fertilizer strategies for wheat cropping in the Victorian high rainfall zone (Dunkeld, Victoria).

Nitrogen lost from cropped land can adversely affect receiving waters. As a result, cropping systems have been developed that increase grower earnings and reduce environmental impacts. In southeastern Australia sheep and cattle grazing lands are being converted to broad-acre, high rainfall (>550 mm) cropping. This land-use change has most likely increased N loss to surface waters from both conventional and raised-bed cropping systems. However, the most appropriate way of mitigating N loss from high rainfall cropping remains unclear.

For an earlier paper we developed a Bayesian Network to compare dissolved N loss from high rainfall cropping (Nash et al., 2010). The network combined subjective and objective information into a conceptually sound model that provided a transparent and logical linking of key management decisions to N loss including estimates of associated uncertainty. In this study we use a slightly modified Bayesian Network, the APSIM (Keating et al., 2003) crop production model, and gross margin analyses to investigate N loss risk, crop yields, and gross margins of wheat crops in the Dunkeld region of southeastern Australia. Crop production and water budgeting were modelled assuming similar sowing conditions each year for 120 years using climate data from 1889 to 2008. Those data were used: (a) to investigate relationships between environmental and economic objectives associated with N fertilizer use; and (b) to develop recommendations for managing N fertilizers used for growing wheat varieties with different growing season lengths where soils have different pre-sowing N fertility. The scenarios tested included a range of fertilizer application strategies with up-front and in-season applications (**Table 1**).

The environmental impact of the different management systems was estimated on the basis of dissolved N load. The Dissolved N Load Factor is a probability weighted outcome of N loss derived from the described Bayesian network, which considers a range of crop, site, weather and N management options (Nash et al. 2010). It is not a measure of the mass

Table 1. Fertilizer management strategies used to compare economic and environmental attributes of wheat crops in the Dunkeld region.

Management strategy[a]	Sowing	Fertilizer application GS31[a]	GS39[a]	Total
	----------	kg N/ha	----------	
D0 0N	10	0	0	10
D0 25N	35	0	0	35
D0 50N	60	0	0	60
D0 100N	110	0	0	110
GS31 25N	10	25	0	35
GS31 50N	10	50	0	60
GS31 100N	10	100	0	110
GS39 25N	10	0	25	35
GS39 50N	10	0	50	60
GS39 100N	10	0	100	110
D0 25N GS31 25N	35	25	0	60
D0 50N GS31 50N	60	50	0	110
GS31 25N GS39 25N	10	25	25	60
GS31 50N GS39 50N	10	50	50	110

[a]D0 = Sowing, GS31 = Growth Stage 31, GS39 = Growth Stage 39 (Zadoks et al., 1974).

Abbreviations and notes: N = nitrogen.

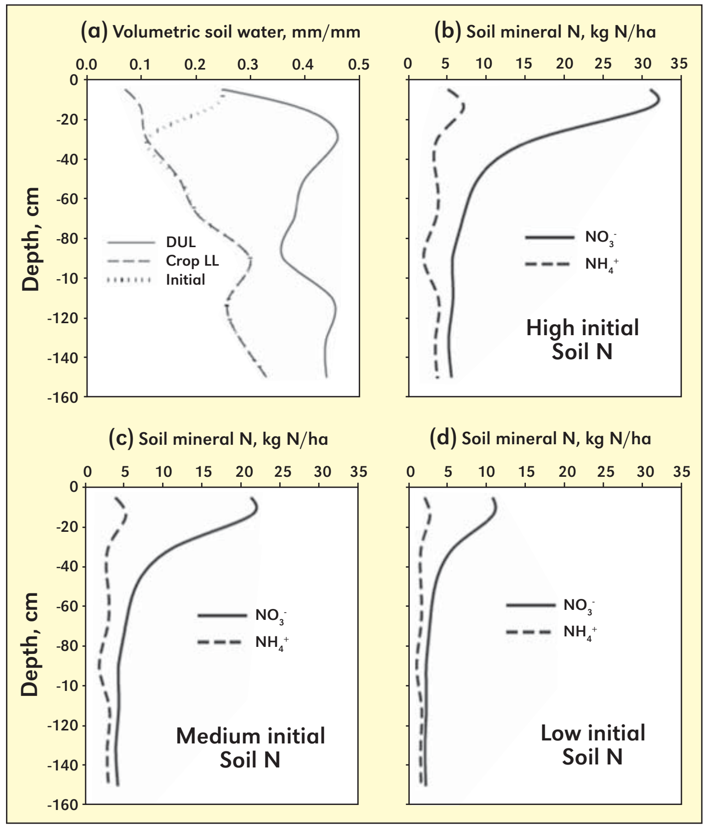


Figure 1. Initial soil water (a) and soil mineral N conditions (b-d) used for the simulations. High, Medium and Low initial soil mineral N conditions are shown in (b), (c) and (d), respectively. DUL = Drained Upper Limit (field capacity); Crop LL = Crop Lower Limit of water availability (permanent wilting point).

of N lost, but a small value indicates a lower probability of nutrient loss than a higher value. The Dissolved N Load Factor was estimated from the initial soil mineral N levels; Low, Medium and High (**Figure 1**), and fertilizer rates and timing. The study considered three varieties of wheat: "Silverstar®"(short season); "Chara®"(mid-length season), and; "Mackellar®" (long season).

Mackellar is a 'red' wheat and therefore used for animal feed, whereas Silverstar and Chara are potentially milling wheats. Because of differences in grain prices, returns from these three cultivars were different, although the impacts of N management on returns and dissolved N load were similar between the medium and long season wheats, but the modelling suggested that Dissolved N Load Factor was higher for the short season type Silverstar.

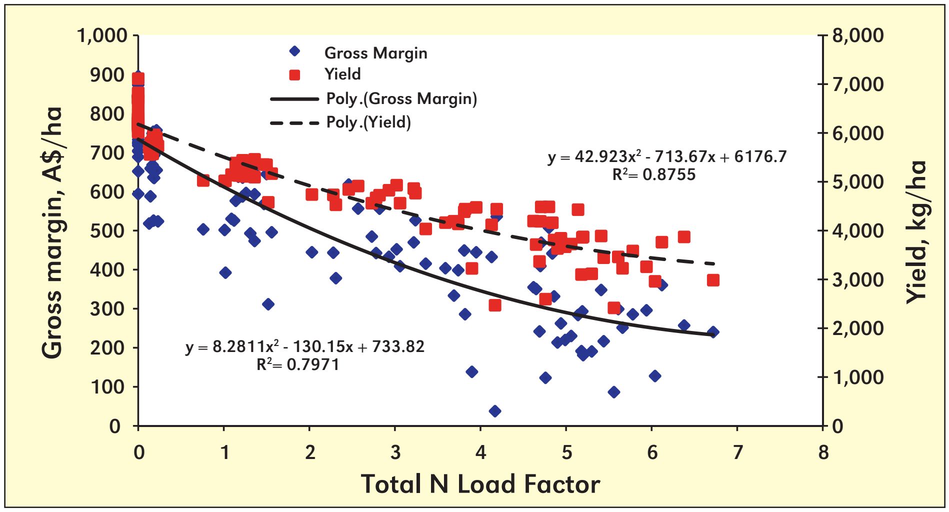


Figure 2. Plots of estimated average annual yields and gross margins against estimated environmental impact (Dissolved N Load Factor) from Dunkeld in southeastern Australia with data for the low initial soil N, 10 kg N/ha at sowing options.

Overall, irrespective of fertilizer application rates, crops grown on soils with higher initial N concentrations are generally higher yielding. Applied N, initial soil N and wheat variety affected gross margin estimates ($p = 0.001$). Overall gross margins increased with fertilizer application rate from A$264 to $444, $539, and $602/ha for the 10, 35, 60, and 110 kg N/ha application rates with strong linear ($p = 0.001$) and quadratic components ($p = 0.001$) to the relationship. The Dissolved N Load Factor decreased with increasing initial soil fertility (i.e., 4.0, 2.0 and 0.4 for the low, medium and high initial soil N, respectively) and with increasing applied N (4.4, 3.2, 2.2, and 1.0 for 10, 35, 60, and 110 kg N/ha, respectively).

Table 2. Analyses of gross margins and environmental performance for the wheat cultivar 'Chara' grown with different fertilizer application rates and fertilizer application strategies using data derived from APSIM modelling and the use of a cropping Bayesian Network.

Soil N	Total fertilizer N added, kg/ha	Gross margin, A$/ha	Dissolved N Load Factor (unit-less)	Sustainability Rating	Recommendation
Low	110	576	1.1	505	An additional 50 kg N/ha at sowing and an additional application (50 kg N/ha) at GS31[a]. SEE NOTE 1
Medium	50	750	0.2	>3000	Two post-sowing applications of fertilizer (25 kg N/ha) SEE NOTE 2
					OR
	110	780	0.0	>3000	Two post-sowing applications of fertilizer (50 kg N/ha).
High	50	873	0.0	>3000	Two post-sowing applications of fertilizer (25 kg N/ha). SEE NOTE 3

[a]GS31 = first node stage or Growth Stage 31 (Zadoks et al., 1974).
[1]This recommendation reflects the reduction in the volume of runoff (due to plant water use) that accompanies a productive crop.
[2]Rating based on maximum flexibility.
[3]This option provided the best overall flexibility, was within A$30/ha of the highest gross margin and low environmental risk.

These results imply that the reductions in drainage volumes from improved crop growth have a greater impact on N loss than the increased N concentrations resulting from the additional fertilizer N used to achieve that extra growth. This subsequently leads to a strong negative relationship between gross margins and the Dissolved N Load Factor (**Figure 2**). We subsequently calculated a Sustainability Rating by combining the Dissolved N Load Factor and gross margins, simply dividing the latter by the former, and developed a set of recommendations and conditional comments for likely cropping scenarios (**Table 2**).

This work suggests that flexible management of N fertilizers with the aim of maximizing gross margins will also lead to enhanced sustainability outcomes. BC

Dr. Nash (e-mail: david.nash@depi.vic.gov.au), Rob Harris and Penny Riffkin are Research Scientists at the Victorian Department of Environment and Primary Industries, Ellinbank, Hamilton, and Hamilton (respectively) Victoria, Australia. Alan Blackburn is a consultant with Alan Blackburn and Associates, Geelong, Victoria; Cam Nicholson is a consultant with Nicon Rural Services at Queenscliffe, Victoria and Mark McDonald is CEO of Southern Farming Systems, Inverleigh, Victoria.

This article is an abridged version of the journal article, Nash, D, P. Riffkin, R. Harris, A. Blackburn, C. Nicholson and M. McDonald, 2013. Europ. J. Agronomy, 47, 23-32.

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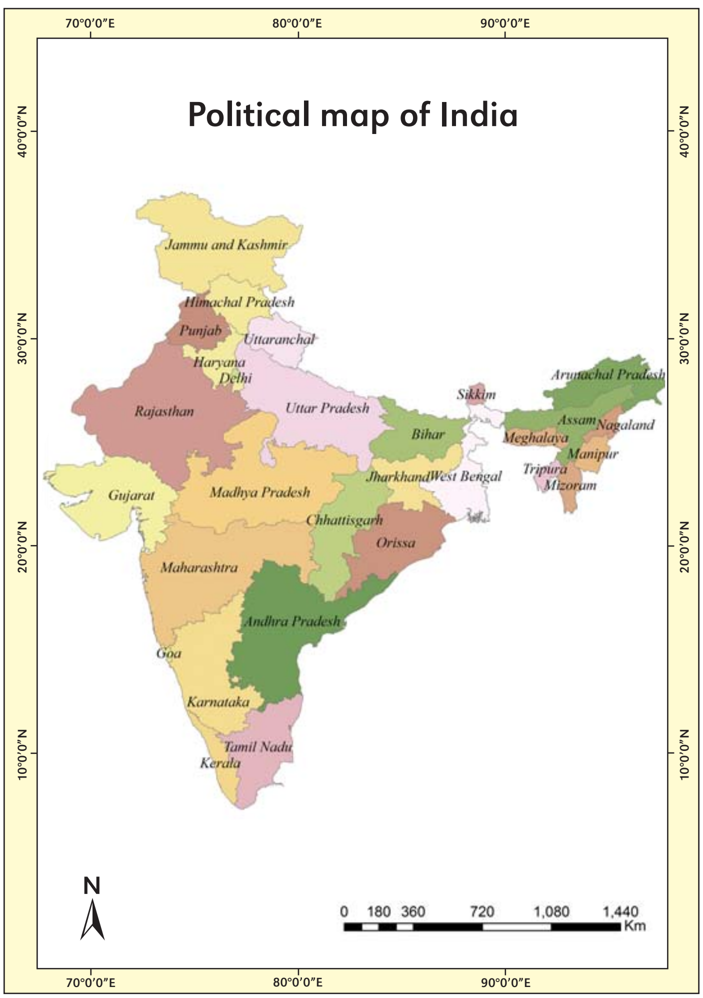
Mapping Potassium Budgets Across Different States of India

By Sudarshan Dutta, Kaushik Majumdar, H.S. Khurana, Gavin Sulewski, Vidhi Govil, T. Satyanarayana, and Adrian Johnston

Potassium input-output balances in different states of India were estimated and mapped using the IPNI NuGIS approach. Results showed negative K balances in most of the states suggesting deficit K application as compared to crop K uptake. Deficit application of K contributes to nutrient mining from soil, results in the depletion of soil fertility, and may significantly limit future crop yields.

Agricultural systems in India intensified significantly after the country's independence in 1947. Although net cultivated area remained stable at 140 million (M) ha, the area sown more than once increased from about 14 M ha in 1951-52 to 52 M ha in 2009-10 (FAI, 2012). This was largely made possible through the increase in irrigation facilities as the share of gross irrigated to gross sown area increased from 17 to 45% during the same period. This period also witnessed the introduction and large-scale adoption of high-yielding and hybrid crop varieties with far higher yield potentials than the local varieties, and a concomitant increase in fertilizer nutrient use in crops. Food grain production increased five-fold, from 51 M t in 1950-51 to over 250 M t at present, while fertilizer nutrient ($N+P_2O_5+K_2O$) consumption increased by nearly 400 times during the same period. Such rapid growth in crop production and fertilizer consumption can cause a mismatch between nutrient application and nutrient off-take from agricultural soils supporting such high crop production growth. This is especially true for K as, historically, K application to crops in India has remained inadequate while K requirements of most crops are equal to or more than their N requirements.



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

Several studies have highlighted the disparity between nutrient input-output balances in Indian soils (Biswas, and Sharma, 2008), and widespread deficiency of plant nutrients in soils (Samra and Sharma, 2009). The All India Coordinated Research Project on Long Term Fertilizer Experiments by the Indian Council of Agricultural Research have shown negative K balances even at the optimum NPK application rates across India (Sanyal et al., 2009). Tandon (2004) estimated an annual depletion of 10.2 and 5.97 M t K_2O from Indian soils on a gross and net basis, respectively. He suggested that out of the net negative NPK balance or annual depletion of 9.7 M t, N and P depletion was 19 and 12% respectively, while a 69% depletion was shown for K. Later, Satyanarayana and Tewatia (2009) calculated state-wise nutrient balances in India and showed negative K balances in different states ranging from -0.1 to -1.1 M t.

The above studies highlighted that K application in Indian soils is much less than K off-take by crops, thereby leading to mining of native soil K. The general assumption that most Indian soils are well supplied with K and do not require any K application may not hold true for intensive cropping systems now practiced in the country. A soil well supplied with K for a yield level of 1 to 2 t/ha may turn out to be deficient in K as the yield target moves up due to the availability of better seeds, management options etc. This clearly indicates the necessity of assessing K balance periodically in intensively cropped areas to avoid unwanted decline in soil fertility levels. Earlier studies that assessed the yearly K balances in soils of India used different methodologies, which does not allow an assessment of change in K status with time. The present study utilized standard data sources and methodologies to assess the changes in K balance across

Table 1. Crop K_2O removal per unit of crop yield.

Crop	K_2O removal, kg/t
Wheat*	20.00
Rice*	15.90
Maize*	17.40
Barley	6.70
Gram*	25.81
Arhar	62.50
Moong*	25.81
Masoor*	18.35
Moth*	25.81
Groundnut	8.51
Sesame	2.54
Mustard	11.00
Linseed	11.62
Cotton*	14.80
Sugarcane*	1.44

Source: http://nugis-india.paqinteractive.com
*Removal includes crop residue.

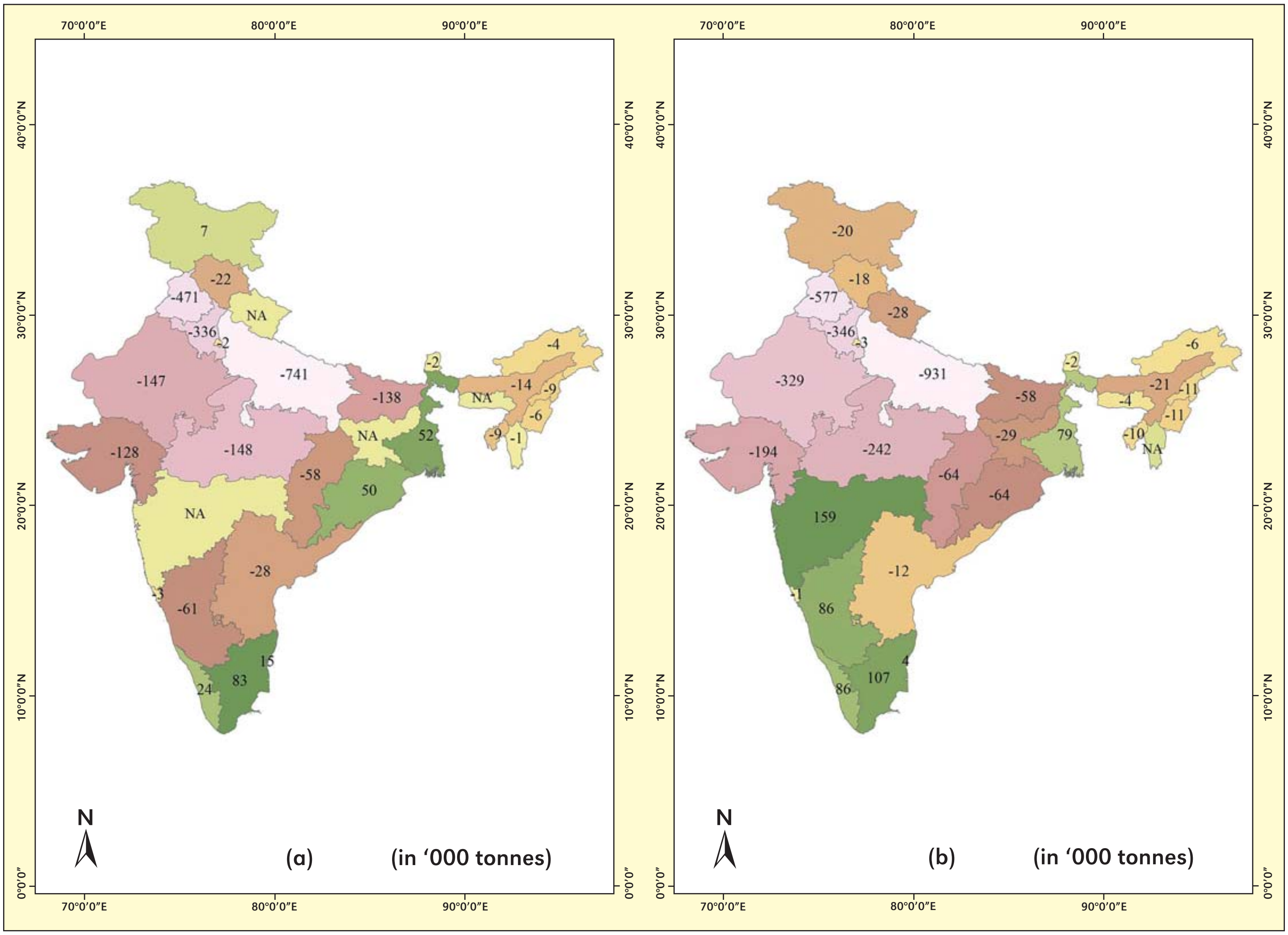


Figure 1. The K_2O balances (applied fertiliser – crop removal) for (a) 2007 and (b) 2011 across different states of India.

different states of India over a four-year interval (i.e., 2007 to 2011).

Determination of K Budgets

The study analyzed the amount of potash fertilizer received by agricultural soils through inorganic and organic sources, the removal of K by different agricultural crops, and estimated the K budget that determines the K accumulation or removal from soil. Data on fertilizer use and the total amount of recoverable manure used in different states were obtained from the Agriculture Census Division, Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India website (http://inputsurvey.dacnet.nic.in/districttables.aspx) as well as from the publications of the Fertiliser Association of India (FAI, 2007 and 2011). Information on district-wise K_2O consumption, through inorganic sources and recoverable manure, were accessed from the above two sources. The amount of manure consumed in each district was multiplied by a suitable factor, based on average K content in recoverable manure, to estimate the K_2O contribution from organic sources.

The K_2O removal by crops was calculated by multiplying production with K_2O removal per unit of production. **Table 1** describes the K_2O removal per unit production for different crops used for calculation of State-wise K_2O removal in this study. The data source was Special Data Dissemination Standard Division, Directorate of Economics & Statistics Ministry of Agriculture Govt. of India, (http://apy.dacnet.nic.in/crop_fryr_toyr.aspx) and FAI (2007; 2011). The major crops considered in this study were rice, wheat, maize, barley, gram, arhar (tur), moong, masoor, moth, groundnut, sesame, mustard, linseed, cotton, and sugarcane. Potassium removal by horticultural crops was not considered in the K balance estimations.

The K_2O balances were calculated for different states for the years 2007 and 2011 by calculating the difference between the amount of K_2O applied to soil in the form of fertilizer and the crop removal values across different states. These values were then mapped using Arc-GIS 10.1 (ESRI, 2012).

Potassium Balance Comparison across Different States

The K_2O balances without manure for 2007 and 2011 are shown in **Figure 1** where negative balance indicates K depletion from soil while positive balance indicates build up. It is evident that K depletion was more significant in 2011 compared to 2007 in most of the northern (such as Punjab, Haryana, Uttar Pradesh), eastern (Assam, Odisha, Tripura) and western (such as Gujarat, Rajasthan) states of India. Soils of these states typically receive less than the required amount of K. Interestingly, the K_2O balances were negative in Bihar in the year 2007 as well as for Bihar + Jharkhand (Jharkhand was part of Bihar in

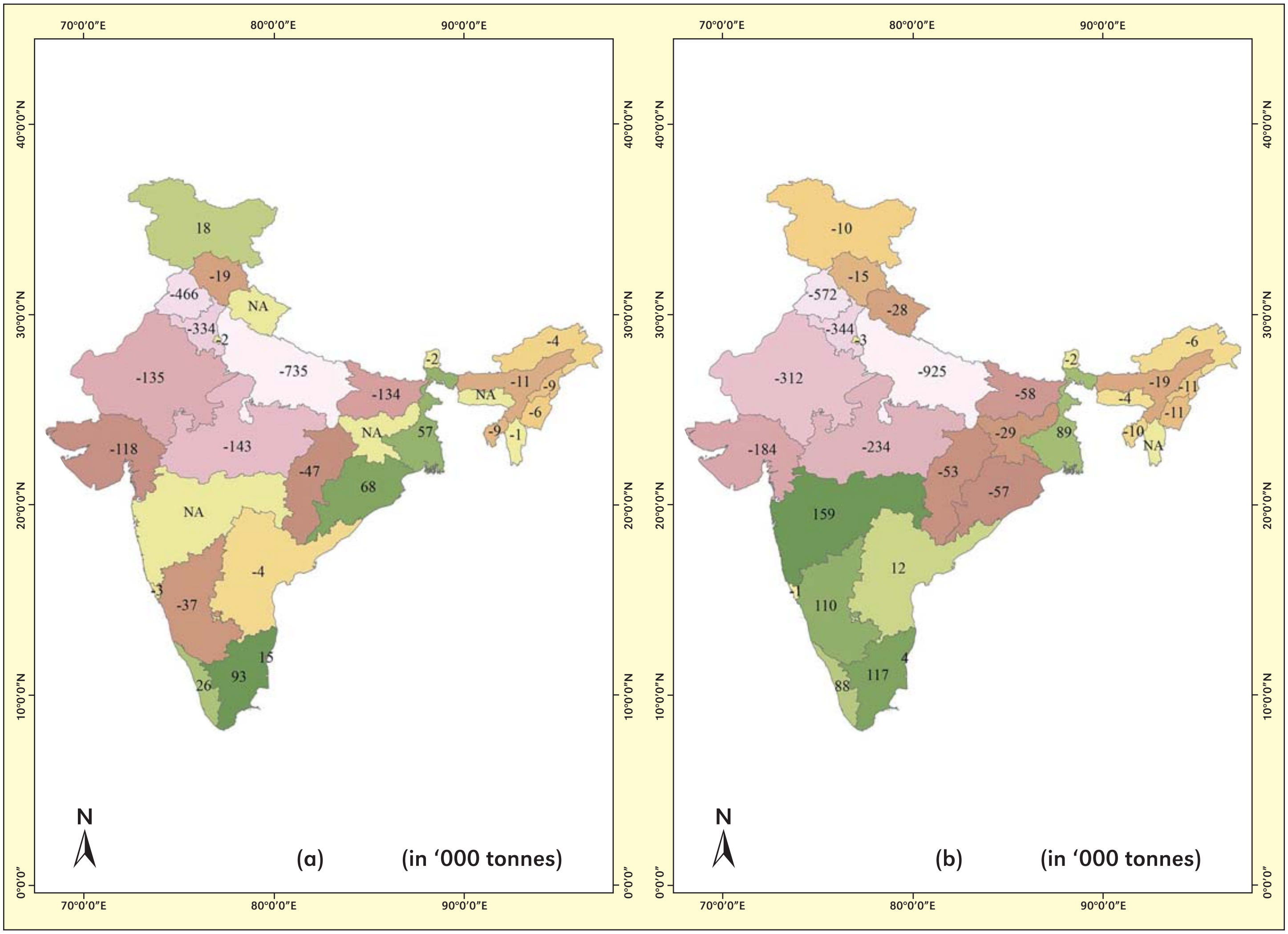


Figure 2. The K_2O balances (applied fertiliser + manure – crop removal) for (a) 2007 and (b) 2011 across different states of India.

2007) in 2011, but the negative K_2O balance has decreased from 2007 to 2011 — an indication that there was increase in the K_2O consumption and/or fertilization practices. A similar trend was also observed in the case of Andhra Pradesh. The states of West Bengal and Tamil Nadu show positive K_2O balance in both 2007 and 2011. Surprisingly, a huge change in K_2O balances was observed in Karnataka and Odisha; while Karnataka showed positive balance, and a large change towards negative balance was observed in the case of Odisha. Review of available data showed that Uttar Pradesh produced 41 M t of foodgrain using 0.17 M t K_2O in 2007; whereas, in the year 2011 the total foodgrain production was 51 M t with total K_2O consumption of 0.27 M t. Therefore, on average, 4 to 4.5 kg of K_2O was applied per t of food grain production, which is much less than the required amount. This might be the reason for the increasingly negative K_2O balance in Uttar Pradesh (**Figure 1 and 2**). On the other hand, Andhra Pradesh produced 19.3 M t of foodgrain in 2007 using 0.34 M t K_2O; whereas, in the year 2011 the total foodgrain production was 20.1 M t with total K_2O consumption of 0.35 M t. Therefore, on average, 17 kg K_2O was applied per t of food grain production. This might have lead towards more balanced K application for the state and a less negative balance in 2011 as compared to 2007.

Figure 2 illustrates the K_2O balance by including the manure application across different states of India. As expected, our results highlight that inclusion of manure input improves the K balance for all states; however, this does not cause much change in the K_2O balance values for most of the states except Andhra Pradesh, where positive K_2O balance was observed in 2011 only after inclusion of manure application. Availability of organic manure for field application is limited in India because of competitive use of organic resources for fodder, fuel and other domestic purposes.

Our study highlighted that the K_2O balance was negative for most of the states across India in the year 2007. These negative values increased in the year 2011 probably due to less fertilizer application and/or higher crop production. Such depletion may not be immediately apparent through assessment of available K in soils as such depletion may occur from the non-exchangeable pool of soil K that is usually not measured during soil testing. Indeed, such unnoticed depletion of K from the soil may seriously deplete the K fertility status of the soil that will require much higher future investment to restore the fertility levels. Studies have shown that excessive depletion of interlayer K may cause irreversible structural collapse of illitic minerals, thereby severely restricting the release of K from such micaceous minerals (Sarkar et al., 2013). Indian soils in general, and the alluvial soils in particular, are rich in micaceous minerals that attribute high K supplying capacity to these soils. However, there is a threshold value of K depletion a soil could support, beyond which any further depletion would cause irreversible loss of K fertility levels, a major soil quality parameter. This may adversely affect the productivity of these soils.

Summary

Our study highlighted negative K_2O balances in many Indian states, which increased in 2011 compared to 2007. Therefore, adequate and balanced application of K is required to reverse the trend of K depletion in Indian soils. Potassium application needs to be based on assessed indigenous K supplying capacity, that varies spatially and temporally, and the K requirement for achieving specific yield targets of a particular crop. This will ensure sustained crop productivity and maintenance of soil health. BC

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2014 IPNI Scholar Award Program for Graduate Students

The International Plant Nutrition Institute (IPNI) is pleased to announce the availability of its IPNI Scholar Award program for 2014.

"We are proud to be able to continue to offer these awards as they clearly have many positive benefits," explained IPNI President Dr. Terry Roberts. "For students in the middle of, or just beginning, their research programs the Scholar Award provides a well deserved nod of encouragement. These awards are made possible by our member companies and are evidence of their respect for science."

The IPNI Scholar Award requires students who are candidates for either a M.Sc. or Ph.D. degree in the disciplines of soil and plant sciences including agronomy, horticulture, ecology, soil fertility, soil chemistry, crop physiology, and other areas related to plant nutrition to **submit an application and supporting information by April 30, 2014**. The application process is available on-line only. Recipients will be announced in September, 2014.

Individual graduate students in any country where an IPNI program exists are eligible. Only a limited number of recipients are selected for the award, worth US$2,000 each.

For more information about past winners of the IPNI Scholar Award, plus details on requirements for eligibility and the application procedure, please see our Scholar awards website: www.ipni.net/scholar. BC

Best Management Practices for Nitrogen Fertilization of Potatoes

By Libby R. Rens, Lincoln Zotarelli, and Daniel Cantliffe

With the tightening of profit margins and the desire to reduce environmental impacts, application timing and rates become an important strategy for growers to increase efficiency of fertilizer use and to reduce N-leaching. The potato research team at the University of Florida is developing BMPs to increase N use efficiency for potato production and to reduce N losses to the environment.

With approximately 25,000 acres of winter and spring potatoes, Florida is an integral part of the supply chain for freshly harvested potatoes in the United States, providing over a third of the nation's spring potatoes. Fertilizer for potato production in Florida accounts for more than 15% of the total production cost while cost for N fertilizers has increased by up to 350% since 2000 (USDA-NASS, 2013). Available N in the soil is highly soluble and is prone to leaching in Florida's sandy soils, especially during large rainfall events; therefore N application should be targeted to times of highest plant uptake to increase efficiency.

Nitrogen use efficiency has been well characterized for potatoes grown in the cooler climatic conditions of the Pacific Northwest. In contrast, the climate in northeast Florida is considerably warmer, which results in a shorter growing season where potatoes are planted during late winter and the season extends through early June. Seepage irrigation is utilized as a traditional method for water supply. Nitrogen fertilizer is traditionally applied to the soil at three key stages to supply the crop: first at about 30 days before planting when the field is being fumigated, second at plant emergence, and third when the plants are in vegetative growth stage (6 to 8 in. tall).

A study was conducted in 2011 and 2012 aimed at determining an optimal N rate for commercial potato production for Florida. Both years were characterized by overall rainfall below the historic average. This study was performed with grower collaboration in three locations throughout northeast Florida growing potato variety 'Atlantic.' Each field was supplied water through a seepage irrigation system. In this system, water is applied to the field along furrows (shallow open ditches) spaced every 16 planted rows (60 ft.) throughout the field. Water then permeates down through the soil profile and water table is raised up from an impermeable layer to just below the root zone, allowing soil capillary action to bring the water up into the range of the roots.

The experimental design was factorial with two factors: N rate at plant emergence and sidedress N rate at the 6 to 8 in. growth stage. In accordance with common grower practice, all plots received 50 lb/A of N as ammonium-nitrate (AN 34%N) at fumigation (about 30 days before planting). At plant emergence, 20 to 30 days after planting, the second application of N was applied at 0, 50, 100, or 150 lb/A from liquid urea ammonium nitrate (UAN 32%N). Subsequently, 40 to 50 days after planting, the final application of N (UAN) was sidedressed at rates of 50 to 100 lb/A. Total seasonal N rates ranged from 100 to 300 lb/A. The potato season was broken into six key stages, with soil and/or tissue sampling occurring at each: 1) Fumigation and pre-plant fertilization, 2) Planting, 3) Plant emergence and fertilization, 4) 6 to 8 in. stage and final fertilization, 5) Full flower, and 6) Harvest. Nitrogen content within the soil and N uptake into the plant were monitored throughout the season and potato yields were compared among treatments for the two years of the study.

Abbreviations and Notes: N = nitrogen; ppm = parts per million; BMPs = Best Management Practices. IPNI Project #FL30.

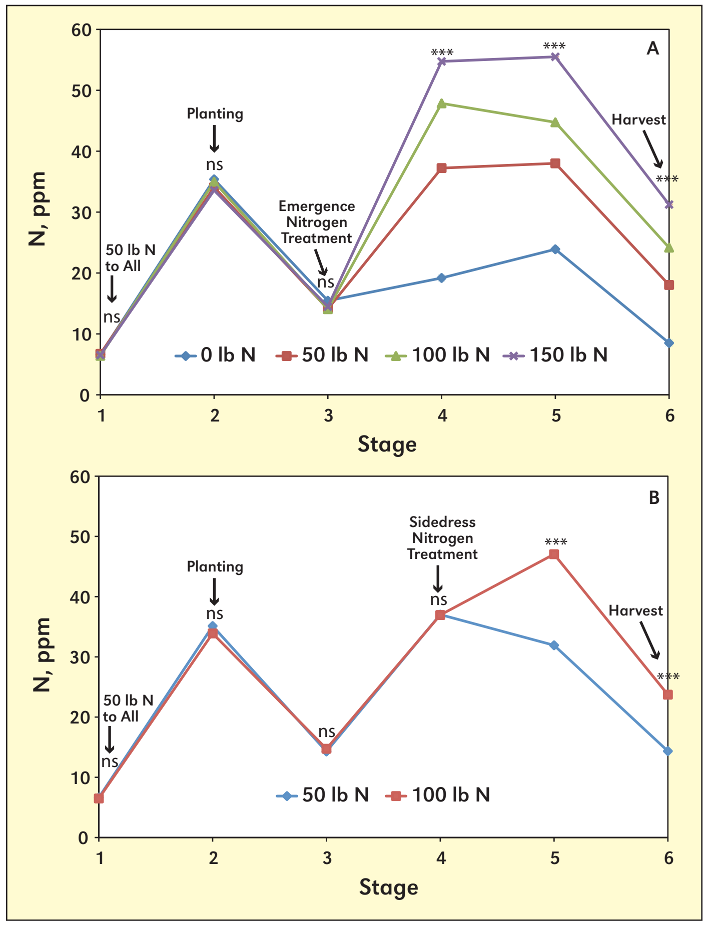

Figure 1. Soil mineral N content at 0 to 8 in. soil depth layer. Soil N content in response to emergence N rate application (A) and sidedress N rate application (B). ns = not significant, *** = p = 0.0001.

Soil Nitrogen Content

Soil N content throughout the season is shown in **Figure 1**. Before the potato seasons started the residual soil N was about 7 ppm mineral N (nitrate and ammonium). The preplant application of 50 lb N/A to all treatments increased the soil N to 34 ppm measured at planting. This residual decreased by more than 50% before plant emergence. Reduced soil N

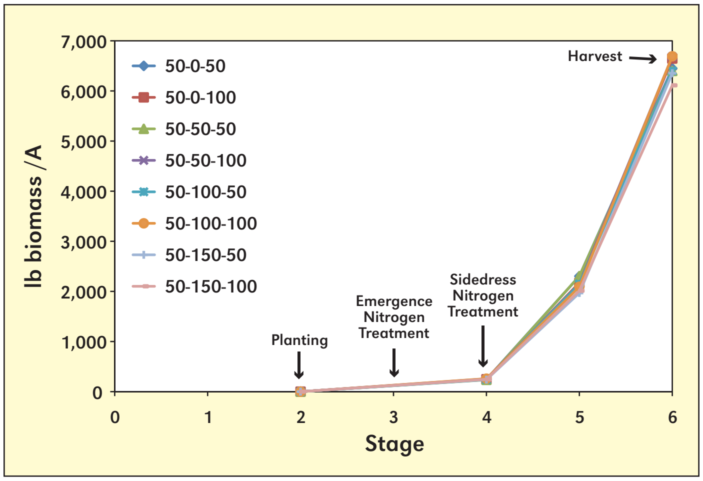

Figure 2. Total plant dry biomass (leaves, stems and tubers). There were no significant main effects or interactions from emergence N rate or sidedress N rate on plant biomass. $p = 0.05$.

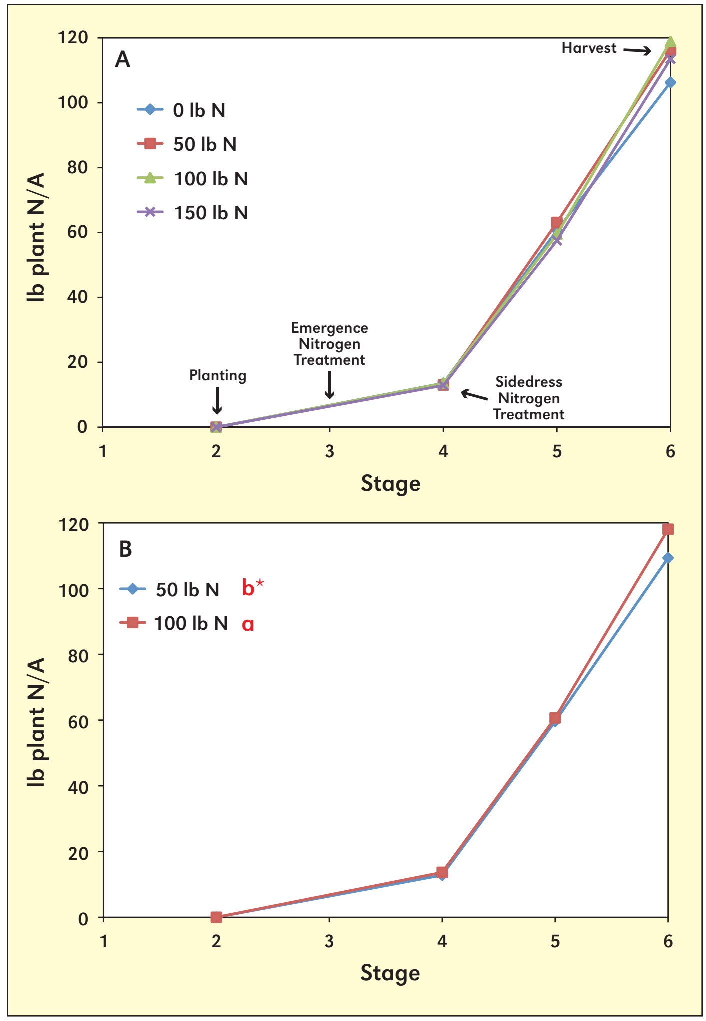

Figure 3. Plant N accumulation (aboveground and tubers). A) There were no significant effects on plant N accumulation due to emergence N. B) Plant N accumulation in response to sidedress N. *Treatments with the same letter are not significantly different at $p = 0.05$.

content coincided with recent heavy rainfall events. Previous research has shown that potato plants do not draw N out of the soil until plant emergence, and rely on the seed-piece up to that point (Ewing, 1978). However, **Figure 1** shows that N concentration in the soil has decreased between stage 2 and 3, despite the fact that the plants were not taking it up from the soil during this time. As plant emergence did not occur until approximately 60 to 70 days after the first N application, it is likely that N has been lost due to leaching through the soil profile due to heavy rains, or volatilization into the atmosphere.

Following N treatments at emergence and 6 to 8 in. growth stage, soil N increased relative to N treatment application. Fertilizer rates above 200 lb N/A left 22 to 39 ppm mineral N in the soil after harvest.

Plant Biomass and Nitrogen Content

Fertilization treatments at emergence or 6 to 8 in. growth stage had no effect on plant dry biomass and by the end of the

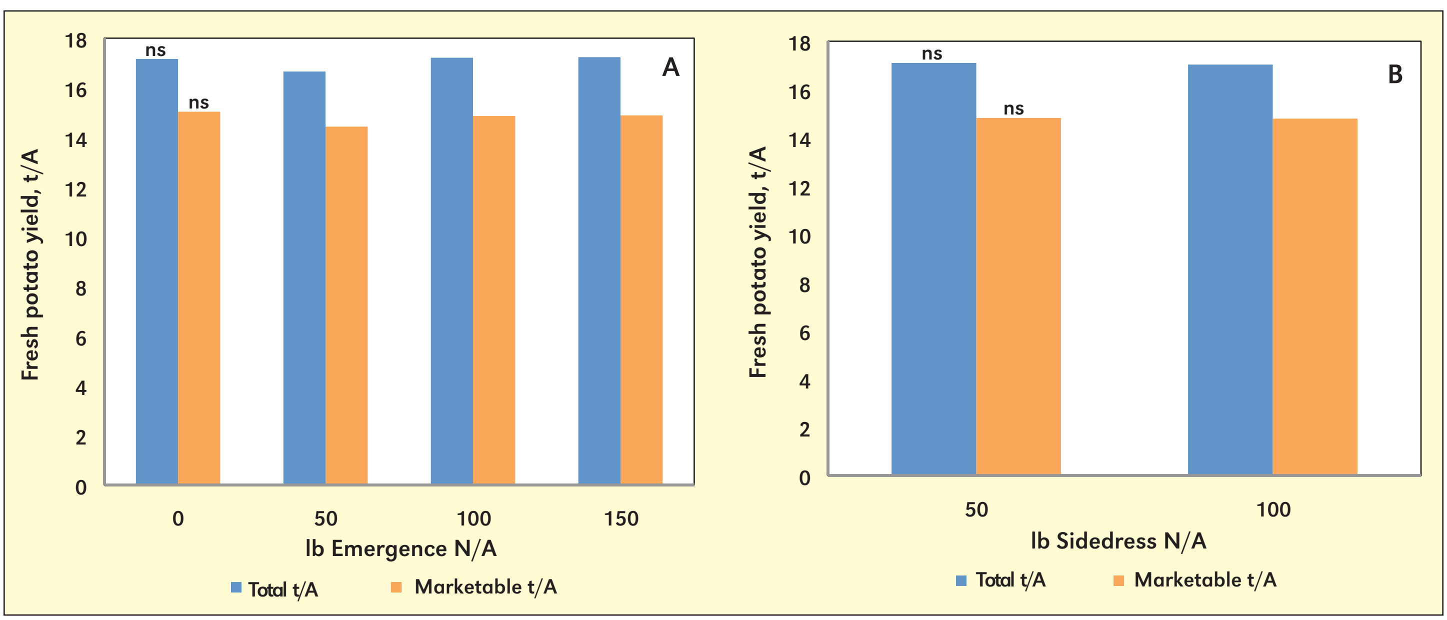

Figure 4. Total and marketable potato yield. A) Emergence N application had no main effect on potato yield. B) Sidedress N application had no main effect on potato yield. $p = 0.05$.

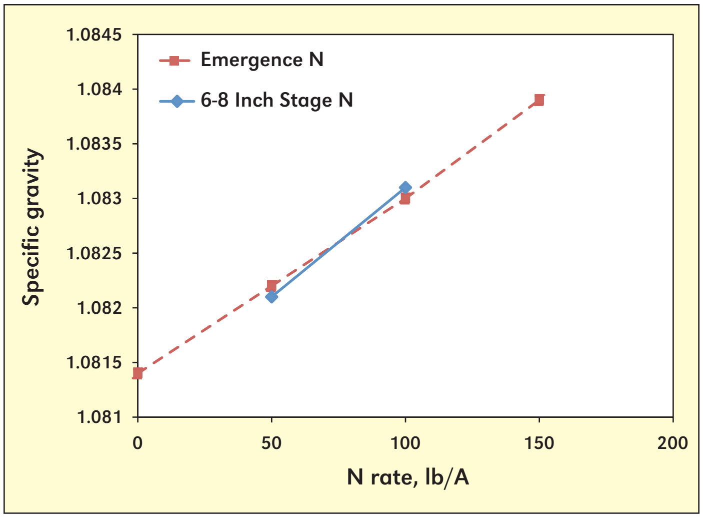

Figure 5. Specific gravity of potato from N treatments at plant emergence and 6 to 8 in. growth stage.

season the potato crop accumulated an average of 3.2 t/A of dry biomass (**Figure 2**). The potato tissues (leaves, stems and tubers) accumulated 98 to 111 lb N/A of over the season (**Figure 3**). There was no difference in plant N accumulation from the emergence N application. At the 6 to 8 in. growth stage the addition of 100 lb/A as compared to 50 lb/A slightly increased plant N, without an increase in potato yield (**Figure 4**).

Yield

Total potato fresh yield ranged between 16.5 and 17 t/A with no difference in yield from the N fertilizer rates at either application stage. Potato specific gravity was affected by both fertilizer applications, with higher values resulting from higher rates of fertilizer at both the emergence stage ($p = 0.0001$) and 6 to 8 in. growth stage ($p = 0.0001$) (**Figure 5**). Higher specific gravity of tubers is preferred as it indicates higher dry matter content of the potato which benefits the frying process.

Conclusion

In this study potato was supplied with total N rates ranging from 100 to 300 lb/A with treatments varying the levels of N at the emergence and 6 to 8 in. sidedress stages. These treatments were verified with soil N concentration tests reflecting the relative application rates applied.

Nitrogen added at the 6 to 8 in. stage only slightly affected plant N content; however this effect did not carry over into yield. Perhaps the most economically useful result of this study for growers is that there was little effect of the N treatments on Atlantic potato yield in dry years such as 2011 and 2012. This means that growers can save money by applying less N at sidedress without negatively impacting yield in dry years.

The results presented in this paper are part of the research program for BMPs for irrigation and fertilization of potatoes. Complementary studies are being carried out to evaluate the benefits of pre-plant N fertilization as well as irrigation management on potato production in northeast Florida. BC

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2014 InfoAg Conference on Precision Ag Set for St Louis, Missouri

The InfoAg Conference

IPNI invites all with an interest in learning about the very latest agricultural technologies and how these tools are being put to use in production agriculture today to consider attending InfoAg 2014.

Last year InfoAg attendance reached a new record of 1,100 participants. As a reflection of this growth and a desire to build on the momentum generated from the event, InfoAg has been moved from its traditional biennial conference schedule and will be held July 29-31 at the Union Station Hotel in St. Louis, Missouri.

Details on the program for InfoAg 2014, registration, and conference contacts can be found at the website http://www.infoag.org. Additional links for the InfoAg Conference: InfoAg Conference Newsletter: http://infoag.org/subscribe, InfoAg on Twitter: @infoag.

Details on other conferences and meetings organized by IPNI can be found at: http://www.ipni.net/conferences. BC

Planning Winter Wheat Yields Based on the Environment and Nutrient Management

By Alexander N. Esaulko and Elena A. Ustimenko

Results from field studies show that optimization of plant nutrition with N, P and K is an important factor in improving both yield and quality of winter wheat grown in Southern Russia. High yield goal-based NPK application resulted in grain yield increases of 87 to 93%. Two methods for calculating nutrient rates worked well for a yield goal of 4.0 t/ha. Yield goals of 5.0 t/ha and 6.0 t/ha were not attained, but a comparison of the approaches to yield planning suggests a slight advantage for one method over the other.

Setting crop yield goals comprises an understanding of a complex set of interrelated measures. Timely and precise consideration of these measures helps both the achievement of goals for crops yield and quality as well as goals for long-term soil fertility and environmental protection (Esaulko et al., 2013). The goal of crop yield planning is to determine the site-specific yield potential for each crop or variety (Esaulko and Ustimenko, 2012). These data could be obtained through fertilizer response trials in the field; however, crop characteristics obtained in variety trials can also be used (Esaulko et al., 2012; Ustimenko, 2013).

Field experiments at the Stavropol State Agrarian University (SSAU) Research Farm were conducted during 2010-2012 adopting existing regional approaches to setting winter wheat yield goals. Winter wheat variety "Zustrich" was selected, which is a medium maturity (vegetation period 273 to 282 days), medium height variety with good lodging resistance characterized by high environmental plasticity, drought and frost tolerance. It is also a high gluten, high protein variety (i.e., gluten 27 to 28%, protein 12.0 to 13.5%).

Field experiments were conducted on a deep-leached chernozem (Luvic Chernozem) of clay loam texture. Soil pH was close to neutral (average pH_{KCl} = 6.7), soil OM was medium (5.1 to 5.6%), and the soil had medium levels of available P (average 22 ppm P_2O_5) and K (240 to 260 ppm K_2O) extracted with 1% $(NH_4)_2CO_3$ solution. Winter wheat was preceded in the crop rotation by field pea. Field experiments were conducted within a RCB design with three replications. Whole plot size and harvest area were 40 m^2 (10 m × 4 m) and 22 m^2, respectively.

Weather conditions during three experimental years were characterized by nonuniform distribution of precipitation (**Table 1**). Annual precipitation was below the long-term average with the exception of the 2009-2010 agricultural year. Experimental years had elevated temperatures with an annual temperature 1.1 to 1.4°C above the long-term average. The most favorable weather conditions for winter wheat growth and development were observed in 2010-2011. Total precipitation during August, 2010 to July, 2011 was 7% below the long-term average; however, its uniform distribution contributed to optimal water supply to plants and hence the highest grain production. The average air temperature was found to be 10.6°C in 2010-2011, which exceeded the long-term average by 1.4°C. Extremely unfavorable weather conditions were observed in 2011-2012. Nonuniform distribution of rainfall during spring-summer 2012 negatively affected winter wheat production.

Abbreviations and Notes: N = nitrogen; P = phosphorus; K = potassium; KCl = potassium chloride; MAP = monoammonium phosphate; OM = organic matter; ppm = parts per million.

Nutrient Rate Calculations

Two methods were used to calculate nutrient rates based on winter wheat grain yield goals of 4.0, 5.0 and 6.0 t/ha. According to the 1st approach developed by SSAU (Ageev and Podkolzin, 2006), P and K rates were calculated as follows:

$$\text{Nutrient rate } (P_2O_5 \text{ and } K_2O \text{ rate, kg/ha}) = \frac{R - RK_s}{K_f} 100,$$

where:

R = nutrient removal in wheat grain plus straw (P_2O_5 and K_2O, kg/ha) at the planned yield goal;

K_s = coefficient showing P and K recovery from soil reserves by wheat crop at the planned yield goal depending on available P and K levels in the soil (0.47 to 0.66 for P and 0.58 to 0.70 for K);

K_f = coefficient showing apparent crop recovery efficiency of applied nutrient (40% and 70% for P and K, respectively).

Nitrogen rates were calculated using the following updated formula:

$$\text{N rate (kg/ha)} = \frac{R(N) - R_{(P2O5)}K_{s\,(P2O5)}K}{K_f} 100, \text{ where:}$$

K = N removal in wheat grain plus straw/P_2O_5 removal in wheat grain plus straw at the planned yield goal;

Table 1. Distribution of precipitation (mm) during the experimental years according to the Stavropol Weather Station.

	Months												
Years	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	July	Total
2009-2010	85	70	13	68	21	53	36	68	25	94	22	70	625
2010-2011	5	67	83	19	24	19	17	46	52	87	107	54	580
2011-2012	75	11	10	20	20	37	17	37	13	38	96	83	457
Long-term average	54	43	46	41	32	27	34	53	70	90	80	53	623

Table 2. Effect of fertilizer application on yield components of winter wheat (three-year average) in Stavropol.

Treatment	Method of nutrient rate calculation	Yield goal, t/ha	Number of productive tillers per m^2 (NPT)	Number of kernels per spike	Kernel weight per spike, g	1000 kernel weight, g
Control	-	-	373	23	0.98	34.0
$N_{60}P_{60}K_{30}$*	-	-	394	25	0.97	35.2
$N_{60}P_{34}K_{34}$	1	4.0	402	27	1.04	36.4
$N_{68}P_{44}K_{24}$	2		404	25	1.00	36.1
$N_{105}P_{60}K_{60}$	1	5.0	403	26	1.04	36.7
$N_{90}P_{67}K_{40}$	2		425	28	1.03	37.1
$N_{126}P_{80}K_{72}$	1	6.0	432	28	0.99	37.2
$N_{110}P_{82}K_{51}$	2		431	30	1.07	37.5

Note: $N_{60}P_{60}K_{30}$ is a blanket fertilizer recommendation. The 1st and the 2nd approach to nutrient rate calculation were developed by V.V. Ageev (Ageev and Podkolzin, 2006) and by L.N. Petrova et al. (1987), respectively.

K_f = coefficient showing apparent crop recovery efficiency of applied N (70%).

The 2nd approach was developed by researchers from Stavropol Research Institute of Agriculture and Stavropol State Centre for Agrochemical Service. Nutrient rates were calculated as follows (Petrova et al., 1987):

Nutrient rate (N, P_2O_5, and K_2O, kg/ha) =YRKc, where:

Y = winter wheat yield goal, t/ha;
R = nutrient (N, P_2O_5, and K_2O) removal in wheat grain plus straw, kg/t grain;
Kc = coefficient showing nutrient use to removal for wheat grain plus straw (0.49 to 0.52 for N, 1.10 to 1.36 for P, and 0.30 to 0.43 for K depending on the planned yield goal).

Moreover, a zero fertilizer treatment (control) and recommended blanket rates for the agro-ecological zone ($N_{60}P_{60}K_{30}$) were also included into the experimental scheme. Fertilizer applications included basal rates of K applied as KCl before tillage and P fertilizer as MAP at planting. Nitrogen fertilizer was topdressed in early spring as ammonium nitrate.

Results

Three-year averages for yield components of winter wheat are presented in **Table 2**. Results indicate that number of productive tillers (NPT) varied most widely compared to other growth parameters depending upon the level of plant nutrition. NPT improved from 373 to 432 tillers/m^2 due to increasing fertilizer use. Different fertilizer combinations increased NPT by 21 to 59 tillers/m^2 compared to the non-fertilized control. The highest values (431 to 432 tillers/m^2) were obtained in treatments receiving $N_{126}P_{80}K_{72}$ and $N_{110}P_{82}K_{51}$ nutrient rates for the highest yield goal of 6.0 t/ha.

Number of kernels per spike also increased due to fertilizer application and the difference with the control reached 2 to 7 kernels/spike. The highest number of 30 kernels/spike was formed in the treatment receiving $N_{110}P_{82}K_{51}$. Kernel weight per spike also increased through all fertilizer treatments except the recommended blanket rates ($N_{60}P_{60}K_{30}$). The difference with control varied from 1 to 9% depending on fertilizer rates. Similar to the number of kernels the highest kernel weight per spike (1.07 g) was obtained in the treatment receiving $N_{110}P_{82}K_{51}$. Fertilizer combinations positively affected 1,000 kernel weight. Recommended blanket rates ($N_{60}P_{60}K_{30}$) had the lowest effect on the above-mentioned parameter resulting in only 4% increase compared to 6 to 10% in other fertilizer treatments. The heaviest kernels (37.5 g per 1,000 kernels) were formed with the fertilizer combination of $N_{110}P_{82}K_{51}$.

Fertilizers significantly increased winter wheat grain yield in our study because of considerable improvement of the yield components. Grain yield increase over the control ranged from 0.76 to 2.80 t/ha in 2009-2010, from 1.03 to 2.90 t/ha in 2010-2011, and from 0.97 to 2.28 t/ha in 2011-2012 depending upon the fertilizer combination (**Table 3**). Hence, plant nutrition with N, P and K is highly important for winter wheat production on leached chernozems of the region resulting in yield increases of up to 87 to 93%.

Optimization of winter wheat nutrition based on a yield goal of 4.0 t/ha indicates that both methods for calculating nutrient rates allow for quite precise yield planning. A higher grain yield of 4.17 t/ha (three-year average) was obtained in the treatment receiving $N_{68}P_{44}K_{24}$ (i.e., when we used the 2nd method for calculating nutrient rates). Recommended blanket rates ($N_{60}P_{60}K_{30}$) gave a similar yield of 4.16 t/ha. The 1st method for determining nutrient rates resulted in lower productivity of 3.90 t/ha ($N_{60}P_{34}K_{34}$).

Both methods for calculating nutrient rates were also quite reliable when we set a yield goal of 5.0 t/ha. There was a small difference from the average attainable yield that was slightly lower than this planned yield goal. Marginally better yield planning was observed when we used the 1st approach and got

Table 3. Effect of fertilizer application on grain yield and quality of winter wheat in Stavropol.

Treatment	Method of nutrient rate calculation	Yield goal, t/ha	Grain yield, t/ha: 2009-2010	2010-2011	2011-2012	Average	Gluten, %	GDI	Protein, %
Control	-	-	3.06	3.12	2.63	2.94	17.1	80	10.5
$N_{60}P_{60}K_{30}$	-	-	4.59	4.30	3.60	4.16	22.3	73	11.3
$N_{60}P_{34}K_{34}$	1	4.0	3.82	4.15	3.72	3.90	23.7	75	11.0
$N_{68}P_{44}K_{24}$	2		4.18	4.39	3.93	4.17	24.3	72	11.3
$N_{105}P_{60}K_{60}$	1	5.0	5.22	4.63	4.34	4.73	25.5	72	11.5
$N_{90}P_{67}K_{40}$	2		4.63	5.17	4.21	4.67	24.9	73	11.1
$N_{126}P_{80}K_{72}$	1	6.0	5.86	6.02	4.91	5.60	27.0	75	12.5
$N_{110}P_{82}K_{51}$	2		5.68	5.80	4.61	5.36	26.3	73	12.7
$LSD_{0.05}$	-	-	0.37	0.27	0.32				

Note: Three-year averages are given for grain quality parameters. GDI = Gluten Deformation Index.

Experimental plots of winter wheat during 2009 season (4th December).

an average yield of 4.73 t/ha ($N_{105}P_{60}K_{60}$).

However, we revealed considerable differences between attainable yield and the highest yield goal of 6.0 t/ha. The 1st approach to determining nutrient rates allowed an average grain yield of 5.60 t/ha ($N_{126}P_{80}K_{72}$). Grain yield was lower with the 2nd method ($N_{110}P_{82}K_{51}$) and averaged 5.36 t/ha giving an 11% difference from the yield goal. Nevertheless, we didn't reveal significant differences between the above-mentioned treatments. It is important to indicate that attainable yield was much closer to the yield goal of 6.0 t/ha in the year 2010-2011, which had the most favorable weather conditions.

The improvement of winter wheat grain quality has exceptional importance in the region. Data shown in **Table 3** indicate that all nutrient combinations resulted in higher gluten content in grain (by 5.2 to 9.9%) compared to control. The highest gluten content (26.3 to 27.0%) was obtained in treatments receiving high fertilizer rates ($N_{126}P_{80}K_{72}$ and $N_{110}P_{82}K_{51}$). Fertilizer application also contributed to high gluten quality as indicated by the Gluten Deformation Index (GDI). GDI ranged from 72 to 75 units in fertilizer treatments. Significant improvements of grain protein content by 2.0 to 2.2% were obtained only at high fertilizer rates ($N_{126}P_{80}K_{72}$ and $N_{110}P_{82}K_{51}$).

Recommended nutrient combinations for the yield goal of 6.0 t/ha were the most profitable in our study. The Return on Investment (ROI) for these two treatments receiving $N_{110}P_{82}K_{51}$ and $N_{126}P_{80}K_{72}$ was as high as 125% and 131%, respectively (**Table 4**).

Summary

Optimization of plant nutrition with N, P and K is very important in improving both yield and quality of winter wheat grown on leached chernozems in Southern Russia. Both methods for calculating nutrient rates attained the planned yield goal of 4.0 t/ha. Yield goals of 5.0 t/ha and 6.0 t/ha were not attained taking into consideration the average winter wheat production for three years. More precise yield planning could be achieved when nutrient rates are calculated using the 1st method developed by SSAU.

Table 4. Profitability analysis of winter wheat production (three-year average) in Stavropol.

	Treatment		
Index	Control	$N_{126}P_{80}K_{72}$	$N_{110}P_{82}K_{51}$
Grain price, Ruble/t	8,200	9,000	9,000
Gross revenue, Ruble/ha	24,108	50,400	48,240
Production cost, Ruble/ha	13,250	22,410	20,880
Production cost, Ruble/t	4,506	4,001	3,895
Net income, Ruble/ha	10,858	27,990	27,360
ROI, %	82	125	131

Note: US$1 = 32.87 Russian Rubles.

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2013 Crop Nutrient Deficiency Photo Contest Winners

IPNI is pleased to announce the winners of the 2013 Crop Nutrient Deficiency Photo Contest. Photo submissions were strong across all four categories with many excellent examples received from around the globe. In the majority of cases, preference was given to well-photographed entries that provided: (1) a good representation of the impact of the deficiency to the whole plant, (2) adequate soil and/or plant tissue nutrient analyses information, and (3) some details concerning current or historical fertilization at the site.

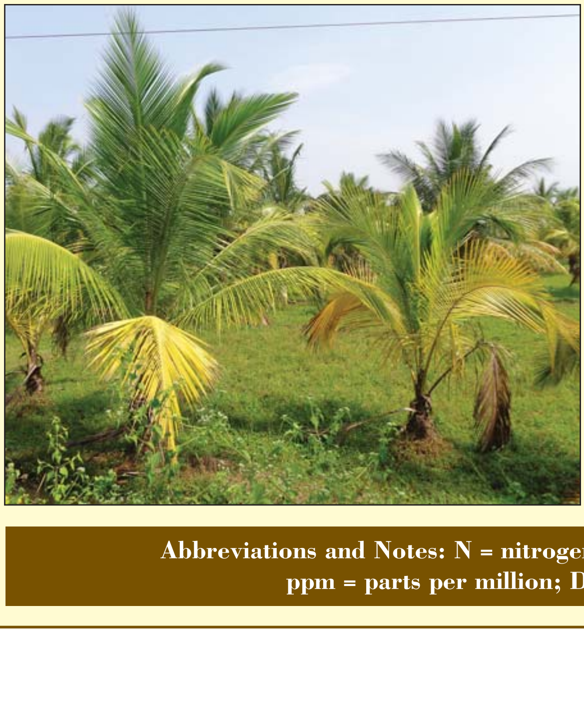
IPNI extends our thanks to all entrants for taking the time to submit their images to this annual contest. We also congratulate all of this year's winners who, in addition to their cash award, will also receive a complimentary version of our most recent USB flash drive collection of nearly 600 crop nutrient deficiency images. For more details on this collection please see: http://ipni.info/nutrientimagecollection.

We encourage all participants to check back regularly with the contest website maintained at www.ipni.net/photocontest for details on submitting your entries for 2014.

Best Overall Image

Grand Prize (US$200) Phosphorus Deficiency in Guava - N.D. Yogendra, University of Agricultural Sciences, Bangalore, India, captured this image of P deficiency in three-year old guava plants (var. Lalith) grown in a P deficient soil at the Regional Horticulture Research and Extension Center. Available (Bray) P content in the soil was quite low (less than 0.9 mg P/kg). Leaf tissue analysis also recorded a low value of 0.065% P. The purpling of guava leaf tissues was due to the accumulation of reddish-purple anthocyanin pigments.

Nitrogen Category



1st Prize (US$150) Nitrogen Deficient Coconut - P. Malathi, Tamil Nadu Agricultural University, Coimbatore, India, provided this shot of N deficiency in coconut. Yellowing of older leaves was noticed in two-year old coconut trees with low soil available N content of 188 kg/ha and total leaf N content of 0.8%.

Runner-up (US$75) Nitrogen Deficient Rice - G.R. Mahajan, Indian Council of Agricultural Research Complex, Goa, India, captured a field image of N deficient rice plants showing yellowing of older leaves followed by younger ones. During the later stages of rice growth, drying of leaf tips was observed. The image was captured from the experiments on organic rice cultivation. Only farmyard manure (FYM) was applied to the rice crop using a N equivalent concept. Lab analysis showed an N content of 0.3% and chlorophyll concentration of 0.64 gram per fresh leaf weight in the youngest fully expanded leaf of this crop. Comparatively, the healthy plant leaves that received both FYM and fertilizer N had 2.7% N content.

Abbreviations and Notes: N = nitrogen; P = phosphorus; K = potassium; Fe = iron; Zn = zinc; ppm = parts per million; DTPA = diethylene triamine pentaacetic acid.

Phosphorus Category

1st Prize (US$150) Phosphorus Deficient Lettuce - J. Hong, Wuhan Institute of Agricultural Sciences, Hubei, China, submitted this close-up shot of P deficiency in lettuce at rosette stage. Some physical and chemical properties of the soil in which lettuce was grown were: pH 7.8, 0.7% organic matter, 3.3 mg/kg available P, 70 mg/kg available N, and 135 mg/kg available K.

Runner-Up (US$75) Phosphorus Deficient Maize - K.M. Sellamuthu, Tamil Nadu Agricultural University, Coimbatore, India, shot this close-up showing P deficiency in hybrid maize (var. CP 808). The deficiency symptoms were observed in 30 day-old maize plants with poor root growth. Soil was acidic (pH 5.3) with low available P (Bray-P) content of 9 kg/ha. Total P content in the leaf tissue was 0.1%.

Potassium Category

1st Prize (US$150) Potassium Deficient Corn - M.K. Rakkar, North Dakota State University, Fargo, USA, submitted this classic example of K deficiency in corn (var. Pioneer 4086) at V8 to V9 growth stage showing chlorosis of outer edges of older leaves. This photo was taken from an experimental plot that received 34 kg K/ha. Soil analysis showed 50 ppm K, while plant analysis recorded the plant tissue K at 0.4%.

Runner-up (US$75) Potassium Deficient Bt Cotton - J. Prabhakaran, Tamil Nadu Agricultural University, Coimbatore, India, shot this characteristic example of K deficiency in Bunny Bt cotton (var. NCS 145) with marginal scorching and reddening of matured leaves. The leaf K content was 1.2%, which was significantly lower than the required K content of 2 to 3%.

Other Category (Secondary and Micronutrients)

1st Prize (US$150) Iron Deficiency in Cowpea - K.M. Sellamuthu, Tamil Nadu Agricultural University, Coimbatore, India, provided this example of Fe deficiency in a 30-day-old cowpea crop. Cowpea leaves exhibited interveinal Fe chlorosis in younger leaves. The experimental soil was a black calcareous soil with low DTPA-extractable Fe of 1.7 mg/kg. Leaf Fe content was 90 mg/kg.

Runner-up (US$75) Iron Deficiency in Guava - K. Venkatesan, Tamil Nadu Agricultural University, Coimbatore, India, submitted this interesting case of Fe deficiency in guava. The deficiency symptoms first appeared in younger leaves as interveinal chlorosis followed by complete chlorosis and then turning into papery white color in severe cases. The soil pH was characteristically high and no micronutrients were applied. The Fe content of a deficient young leaf was 15 ppm, while it was 79 ppm for a healthy leaf.

Leaf Nutrient Analysis as a Management Tool in Yield Intensification of Oil Palm

By Julie Mae Pasuquin, James Cock, Christopher R. Donough, Thomas Oberthür, Rahmadsyah, Ahmad Lubis, Gatot Abdurrohim, Kooseni Indrasuara, Tenri Dolong and Simon Cook

In the BMP trials established in six commercial plantations in Indonesia, the improved nutritional regimes had no consistent effect on leaf nutrient concentrations, and there were no obvious relationships between leaf nutrient status and yield. The authors suggest that Plantation Intelligence™, based on the observation and analysis of farm operations (operational research) and on-farm experimentation principles with data from commercial operations, can be used to adjust critical nutrient levels to fit the particular conditions of commercial blocks.

Leaf analysis is the most common method used to assess the nutrient status of the oil palm crop. Leaf analysis values are usually compared with established critical levels to determine whether a nutrient deficiency exists in the plant. Early researchers defined the critical concentration as not a point, but rather a narrow range of nutrient concentrations that separate the zone of deficiency from adequacy (Ulrich, 1952). Prevot and Ollagnier (1954) gave the critical level a more practical definition as *"the leaf nutrient concentration above which a yield response from fertilizer is unlikely to occur."* From this standpoint, leaf analysis and critical nutrient levels serve as a diagnostic tool to indicate when fertilizer should be applied to the crop.

Various factors affect leaf nutrient concentrations and, hence, critical levels. These include, among others, palm genotypes, soil factors, leaf rank and palm age (Coulter, 1958; Foster and Chang, 1977, Knecht et al., 1977). Some critical levels for N, P and K found in the literature are shown in **Table 1**. Teoh and Chew (1988) provided evidence that rachis K concentration is a better indicator of K nutrient status than leaf K.

Table 1. Critical values for N, P and K in leaf 17 of oil palm.

---- Deficient levels ----			---- Optimum levels ----			
N	P	K	N	P	K	Reference:
2.7	0.15	1.00				Prevot and Ollagnier (1954)
2.5	0.15	1.00	2.6-2.7	0.16-0.17	1.1-1.2	Ng (1969)
2.5	0.15	1.00				Ochs and Olivin (1976)
			2.9-3.0[a]	0.18-0.19	1.1-1.2	Foster and Chang (1977)
			2.6-2.7[b]	0.17-0.18	0.9-1.1	
2.5[c]	0.15	1.00	2.6-2.9	0.16-0.19	1.1-1.3	Von Uexkull and Fairhurst (1991)
2.3[d]	0.14	0.75	2.4-2.8	0.15-0.18	0.9-1.2	
2.6 ; 2.3[e]	0.13		2.5-3.0	0.15-0.19	0.9-1.3	Goh and Hardter (2003)
		1.00[f]			1.3-1.6[f]	Teoh and Chew (1988)

[a]Optimum levels for inland soils of West Malaysia; [b]Optimum levels for coastal soils of West Malaysia; [c]Critical and optimum levels for palms <6 years after planting (YAP); [d]Critical and optimum levels for palms >6 YAP;
[e]Critical level: 2.6 for palms <6 years after planting (YAP); 2.3 for palms >6 YAP; [f]Rachis K

In 2006, the Southeast Asia Program of IPNI evaluated a suite of BMPs for yield intensification of oil palm in large-scale commercial plantations at six sites in Indonesia (**Table 2**). Sites were located in Sumatra (North, South) and in Kalimantan (West, Central and East). The six sites included three with optimal conditions for palm growth and yield (sites 1, 2, 6), and three sites with sub-optimal conditions (sites 3, 4, 5). At each site, five pairs of commercial blocks, each of at least 25 ha, were selected so that each pair was planted in the same year with the same source of planting material and on comparable terrain with similar soil characteristics. In each pair, a block was designated for BMP implementation, while the other became the REF block, where current estate practices were maintained. BMPs related to crop recovery and crop management were implemented in the BMP blocks.

Table 2. General description of oil palm BMP project sites in Indonesia.

			Area, ha		Stand, palms/ha	
Site	Baseline palm age	Annual mean rainfall, mm[a]	BMP[b]	REF[c]	BMP	REF
1	5-12	1,923	266	281	121-140	136-143
2	8-14	3,072	156	160	124-134	122-135
3	15-18	2,782	256	259	127-137	128-135
4	8-9	3,080	143	147	135-149	138-147
5	8-9	3,045	124	121	112-138	128-141
6	3-12	2,509	135	135	133-154	135-146

[a]Climatic variables calculated using long-term averages from WorldClim (Hijmans et al., 2005) by Rhebergen (2012); [b]BMP = best management practices; [c]REF = reference block.

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; BMP = best management practices; REF = reference block; FFB = fresh fruit bunches; EFB = empty fruit bunches. IPNI Project #SEAP-06.

Over four years, nutritional status, fertilizer application, yield and other growth indicators were monitored in each block. Treatment pairs of BMP and REF measured at each site were subjected to analysis of variance (ANOVA). The level of significance used was 5% ($p = 0.05$).

Leaf Nutrient Concentrations

Across years, average leaf N levels in the BMP and REF treatments for sites 1, 2, 3 and 4 were below the published optimum range for N (**Figure 1**). Leaf N was similar between

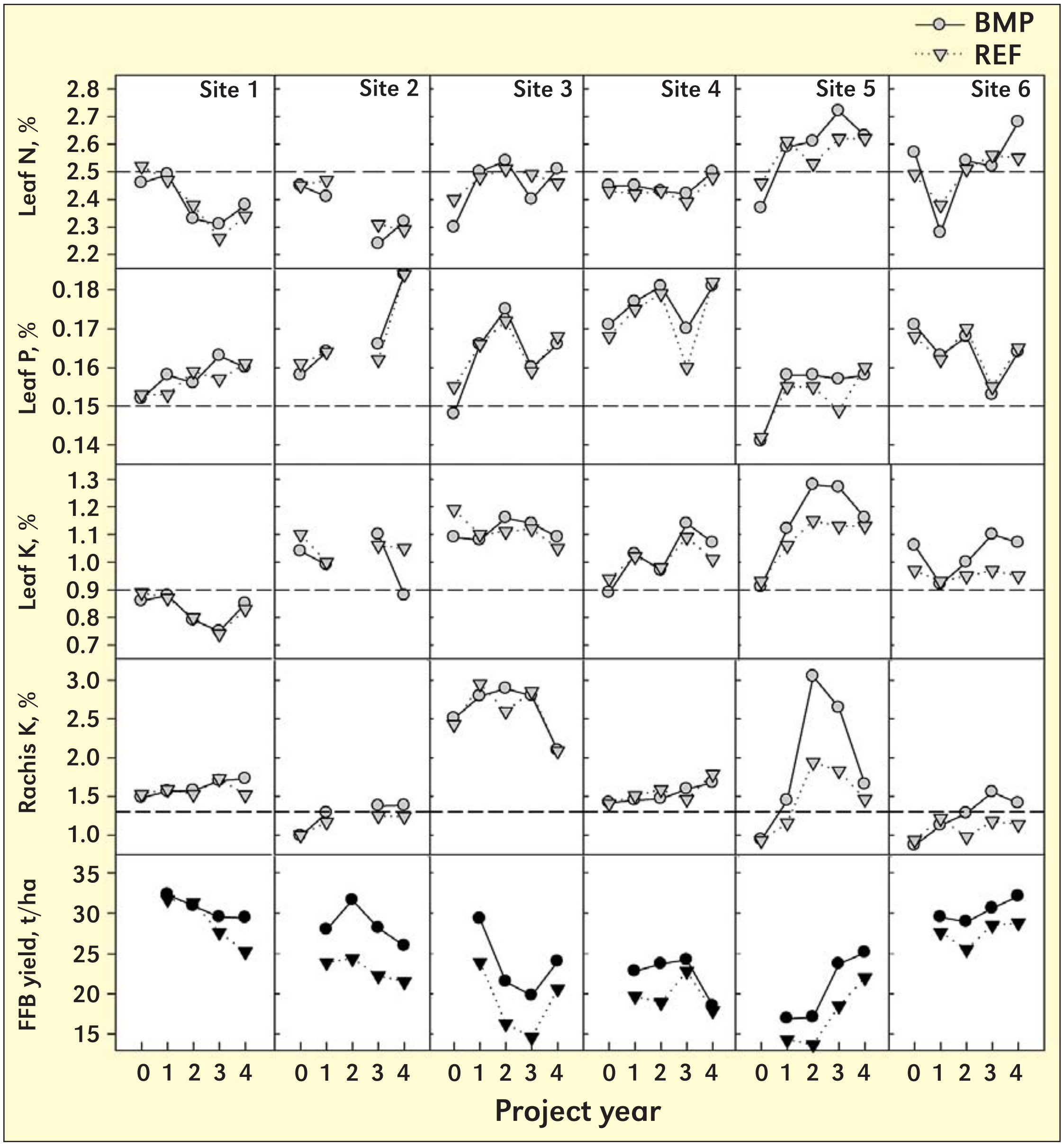


Figure 1. Nutrient concentrations in leaf 17 and rachis, and fresh fruit bunch (FFB) yield in the BMP project. Each data point is the average of five blocks. Broken lines refer to the critical level for N, P and K as given by Goh and Hardter (2003) for leaf 17 and by Teoh and Chew (1988) for rachis. Baseline FFB yield data for all sites and nutrient concentration data for year 2 at site 2 are not available.

BMP and REF in all sites and for most years (**Table 3**). Leaf N levels for both treatments remained fairly constant across years at sites 4 and 6, but declined at sites 1 and 2 and increased at sites 3 and 5.

Leaf P levels for both treatments were mostly within the optimum range (0.15 to 0.19%) at all sites and years. Leaf P levels were similar between BMP and REF treatments, except at sites 4 and 5 where P levels in the BMP were significantly higher than in the REF. In general, leaf P levels increased over time.

Leaf K levels for both treatments were within the optimum range (0.9 to 1.3%), except at site 1 where BMP and REF leaf K values were below the optimum in all years. Leaf K was significantly higher in the BMP treatment at sites 5 and 6, but was similar between the two treatments at other sites. Leaf K levels declined at site 1 during the four years of the project, increased at sites 4 and 5 and remained fairly constant at sites 2, 3 and 6. When averaged across sites, leaf K in the paired blocks were similar at the start of the project; K levels gradually increased in the BMP treatment, but stayed constant in the REF treatment. After the second year of the project, leaf K levels were much higher in the BMP than in the REF.

The apparent K deficiency determined by leaf levels of the BMP and REF treatments at site 1 was not reflected in the rachis K results, with K values within the optimum range of 1.3 to 1.6%. Moreover, whilst leaf K levels were within the optimum range, rachis K levels were outside the optimum range in the REF treatment at site 2 and 6. Across years, rachis K levels were significantly higher in the BMP treatment at sites 2, 5 and 6. Except for site 3, rachis K levels generally increased with time in both treatments. Rachis K in the paired blocks was similar initially, but from the second year onwards the K rachis levels were greater in the BMP treatments. The high rachis K values for all years at site 3 and for years 2 and 3 at site 5 were likely due to the removal of the outer green layer of the rachis during sampling prior to nutrient analysis.

Nutrient Concentrations as a Management Tool

Nutrient levels measured in the leaf and rachis of the treatment blocks reflect neither the differences in yield nor the differential nutrient inputs in BMP and REF. The BMP treatment consistently yielded more FFB than the REF across all sites and years (**Table 3**). The greater yields were attributed to yield-taking BMPs (crop recovery) during the first year and to the combined effect of yield-making (principally improved nutrition) and yield-taking BMPs in later years (Oberthur et al., 2013). The mulching with EFB at a rate of 40 t/ha in the BMP blocks of sites 3, 4, 5, and 6 increased the total nutrient input in the BMP treatment as compared to the REF. However, leaf nutrient levels were not significantly different, particularly for N and P, between BMP and REF within and among sites, in individual years, and averaged across time. Leaf nutrient levels varied over time at some sites; however, the patterns and magnitude of this variation was similar in the REF and BMP treatments. Differences in leaf and rachis K levels between BMP and REF were significant only at certain sites. Also, leaf K results did not correspond well with rachis K results. Site 1 had the lowest total K input among the six sites, which were reflected in leaf analysis results, but not in rachis K levels.

Foster (2003) indicated that nutrient concentrations alone may not be a very good indicator of oil palm nutrient requirements. The lack of a clear association between plant nutrient levels, yield and soil nutrient supply support this view (**Table 3 and Figure 1**). It is possible that increased availability of nutrients increases leaf (or rachis) nutrient content up to a certain level under given conditions, and that beyond that level the plant responds by increased growth with no change in nutrient levels. If this occurs with increased leaf growth leading to greater light interception then yield could increase with no change in nutrient status. This would then suggest that an estimation of the total nutrient content of the fronds, or the total cation content, would be a better indicator of nutrient status as it takes into account both the nutrient concentration and the total growth of the fronds.

Fairhurst and Mutert (1999) suggested that effective fertilizer recommendations are usually the result of combining the results of leaf analysis with field knowledge and common sense. Improvement of field knowledge to relate yield to nutrient contents can be obtained from carefully designed field trials (see, for example, Prabowo et. al., 2010). However, other options exist that may well be less costly but equally effective. The recently developed concept of Plantation Intelligence™ (Cook et al., 2013) as a mechanism to implement operational research and on-farm experimentation is designed to reduce decision uncertainty. This is achieved through a learning process based on the observed performance of individual management blocks in estates. The concept may provide a means to adjust leaf nutrient concentration indicators to suit local conditions. Advances in information technology make it possible to apply operational research principles and on-farm experimentation to agricultural production systems in which record keeping is the norm. If data from commercial operations are routinely collected on leaf nutrient contents, yield, weather and soil conditions on a large number of blocks over a period of time, it should be possible to deduce useful relations between leaf nutrient contents and yields under a particular sets of conditions. Guidelines can then be derived to use leaf nutrient concentrations as a means to determine nutrient requirements adjusted to specific conditions that vary in both space and time. The cyclic nature of the plantation intelligence process of observation, interpretation, evaluation, change etc. provides a built in feedback loop to assess the performance of indicator values and continually improve them in a real production setting.

Due to the large variation in uncontrollable factors that affect production and the multiple management responses required to manage crops within a constantly varying scenario, a large number of data sets for individual blocks

Table 3. Effect of BMP on yield, leaf and rachis nutrient concentrations at six Indonesian plantations (2006-2011).

Parameter	Levels[a]	Treatment BMP	REF	Δ[b]	P>|t|[b]	Effects[c]	P>|F|[c]
FFB yield, t/ha	All	26.0	22.6	3.4	<0.001	Site	0.020
	Site 1	30.5	29.0	1.5	0.017	ProjYr	0.845
	Site 2	28.4	23.0	5.4	<0.001	Site x ProjYr	0.005
	Site 3	23.7	18.9	4.8	<0.001		
	Site 4	22.3	19.8	2.5	0.000		
	Site 5	20.7	17.1	3.6	<0.001		
	Site 6	30.2	27.5	2.7	<0.001		
	Yr 1	26.5	23.5	3.0	<0.001		
	Yr 2	25.6	21.7	3.9	<0.001		
	Yr 3	26.0	22.4	3.6	<0.001		
	Yr 4	25.8	22.6	3.2	<0.001		
Leaf N, %	All	2.46	2.46	0.00	0.834	Site	0.655
	Site 1	2.40	2.40	0.00	0.946	ProjYr	0.021
	Site 2	2.35	2.39	-0.04	0.151	Site x ProjYr	0.864
	Site 3	2.45	2.47	-0.02	0.544		
	Site 4	2.45	2.43	0.02	0.252		
	Site 5	2.58	2.57	0.01	0.556		
	Site 6	2.52	2.50	0.02	0.522		
	Baseline	2.43	2.46	-0.03	0.206		
	Yr 1	2.45	2.47	-0.02	0.434		
	Yr 2	2.49	2.47	0.02	0.324		
	Yr 3	2.44	2.44	0.00	0.878		
	Yr 4	2.50	2.46	0.04	0.048		
Leaf P, %	All	0.163	0.162	0.001	0.043	Site	0.445
	Site 1	0.157	0.156	0.001	0.472	ProjYr	0.447
	Site 2	0.167	0.166	0.001	0.549	Site x ProjYr	0.691
	Site 3	0.163	0.164	-0.001	0.502		
	Site 4	0.176	0.173	0.003	0.013		
	Site 5	0.155	0.152	0.003	0.018		
	Site 6	0.164	0.164	0.000	0.938		
	Baseline	0.157	0.158	-0.001	0.617		
	Yr 1	0.165	0.163	0.002	0.125		
	Yr 2	0.168	0.167	0.001	0.703		
	Yr 3	0.162	0.157	0.005	0.004		
	Yr 4	0.169	0.169	0.000	0.823		
Leaf K, %	All	1.03	1.00	0.03	0.001	Site	0.044
	Site 1	0.83	0.83	0.00	0.974	ProjYr	<0.001
	Site 2	1.05	1.05	0.00	0.925	Site x ProjYr	0.794
	Site 3	1.11	1.11	0.00	0.871		
	Site 4	1.02	1.00	0.02	0.312		
	Site 5	1.15	1.08	0.07	<0.001		
	Site 6	1.03	0.95	0.07	0.001		
	Baseline	0.98	1.00	-0.02	0.193		
	Yr 1	1.01	1.00	0.01	0.498		
	Yr 2	1.04	1.00	0.04	0.027		
	Yr 3	1.08	1.02	0.06	0.001		
	Yr 4	1.05	1.00	0.05	0.006		
Rachis K, %	All	1.72	1.59	0.13	<0.001	Site	<0.001
	Site 1	1.61	1.58	0.03	0.504	ProjYr	0.037
	Site 2	1.26	1.16	0.10	0.022	Site x ProjYr	0.524
	Site 3	2.61	2.58	0.03	0.582		
	Site 4	1.52	1.55	-0.03	0.153		
	Site 5	1.94	1.46	0.48	<0.001		
	Site 6	1.25	1.09	0.16	0.033		
	Baseline	1.37	1.37	0.00	0.916		
	Yr 1	1.61	1.60	0.01	0.601		
	Yr 2	2.05	1.73	0.32	0.002		
	Yr 3	1.95	1.72	0.23	0.005		
	Yr 4	1.66	1.54	0.12	0.094		

[a] All: Combined data averaged for all sites and years.
[b] Δ = BMP – REF; *P*> |t|: probability of a significant mean difference between BMP and REF.
[c] Source of variation of ANOVA of the difference between BMP and REF; *P*> |F|: probability of a significant *F*-value.

must be available to make sense of the trends and tendencies underlying the response of the crop to both management and uncontrollable variation. A direct consequence of this requirement for large data sets are the massive benefits that are obtained from sharing information with peers in other plantations, rather than using it in isolation. To an extent, the success of Plantation Intelligence™ depends on collaboration between various producers. BC

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Global Partnership on Nutrient Management

The accelerated use of N and P is at the center of a complex web of development benefits and environmental problems. They are key to crop production, but excess nutrients from fertilizers, fossil fuel burning, and wastewater from humans, livestock, aquaculture and industry lead to air, water, soil and marine pollution, with loss of biodiversity and fish, destruction of ozone and additional global warming potential. The problems will intensify as the demand for food and bio-fuels increase, and growing urban populations produce more wastewater.

The Global Partnership on Nutrient Management (GPNM)—a partnership of governments, scientists, policy makers, private sector, NGOs and international organizations—is a response to this 'nutrient challenge' of how to reduce the amount of excess nutrients in the global environment consistent with global development. The GPNM recognizes the need for strategic advocacy and cooperation at global level in order to communicate and to trigger actions by governments and other stakeholders in lowering N and P inputs from human activities. It provides a platform for governments, industry, science community, UN agencies and civil society organizations to dialogue and forge a common agenda, mainstream best practices and integrated assessments, so that policy-making and investments are effectively 'nutrient-proofed'.

GPNM's new website is a place where information about this worldwide nutrient challenge is shared with the wider audience. GPNM news items, upcoming events and publications, as well as interesting movies, links to Twitter and LinkedIn accounts and information about ongoing projects. The website also hosts all the results of the UNEP/GEF project "Global foundations for reducing nutrient enrichment and oxygen depletion from land-based pollution, in support of Global Nutrient Cycle" and other initiatives of GPNM Partners. BC

The GPNM website can be found at:
http://www.nutrientchallenge.org

Abbreviations and Notes: N = nitrogen; P = phosphorus; UNEP/GEF = United Nations Environment Programme/Global Environment Facility.

Soil Acidity Evaluation and Management

By Luís Prochnow

Today's agriculture needs to follow the principles of sustainability that include building up and maintaining long-term soil productivity. On soils where acidity limits crop yields, soil and subsoil acidity amelioration constitutes an important part of best management practices (BMPs) to achieve sustainability. A major aspect of soil acidity management is the application of lime, but other practices may also be needed to correctly address the problem. Proper soil acidity management, among other benefits, increases the efficiency of applied fertilizers, improves the effectiveness of some herbicides, protects the environment, and enhances the profit potential for the farmer.

Principles of Soil Acidity

In aqueous systems, an acid is a substance that donates hydrogen ions or protons (H^+) to some other substance. Conversely, a base is any substance that accepts H^+. The H^+ ions, or active acidity, increase with the strength of the acid. The undissociated H^+ contribute to a soil's potential acidity.

Buffer systems can maintain the pH of a solution within a narrow range when small amounts of an acid or a base are added. Buffering defines the resistance to a change in pH. Generally, buffer solution systems are composed of a weak acid (HA) and one of its salts (BA) or a weak base and one of its salts.

Soils differ in terms of active and potential acidity. Also, soils behave like buffered weak acids, with the H^+ in the cation exchange complex (CEC) of humus and clay minerals providing the buffer for soil solution pH.

Figure 1 shows a good example of how soils can differ in terms of lime requirement to reach the same soil pH. For example, while soil B required about 2 t/ha of calcium carbonate ($CaCO_3$) to reach pH 5.5, soil E needed more than 15 t/ha to reach the same soil pH. Obviously, this is related to a much higher buffering capacity of soil E as compared to soil B.

It is important to understand that it is not correct to only rely on soil active acidity as a means to measure the rate of lime to apply. When the soil active acidity is neutralized, there is plenty of acidity to replace it (soil potential acidity or soil buffering capacity). Therefore, it is necessary to correctly evaluate the potential acidity of a soil to accurately measure the rate of lime to apply.

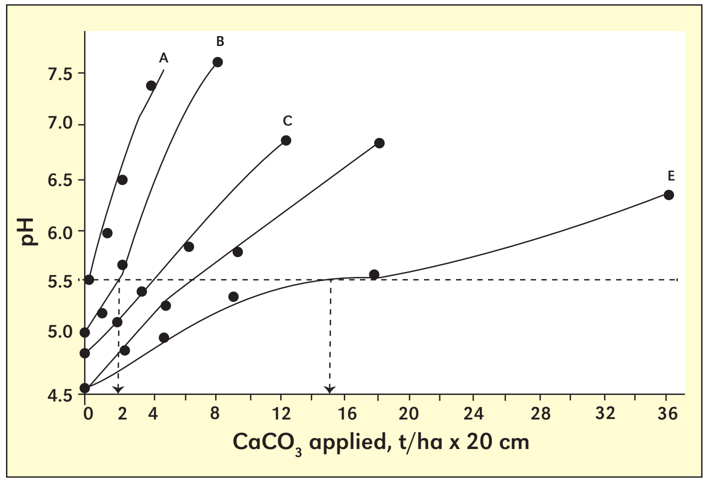

Figure 1. Neutralization curves with $CaCO_3$ for soils with different pH buffering capacities. Raij, 2011.

Why Soils Become Acid

Soils have a natural tendency to become more acid with time. Many factors, both natural (parent material, native vegetation, precipitation, soil depth) and managed (crops grown, N fertilization, organic matter decomposition, tillage, erosion) contribute to increasing soil acidity. If not appropriately controlled, acidity can seriously reduce crop yield, causing significant economic loss to the producer and can have a negative impact on the environment. Problems related to soil acidity are widespread, occurring in many areas throughout the world. It is estimated that about 30% of soils in the world are acidic and represent some of the most important food-producing regions.

Importance of Soil Acidity Amelioration

Proper use of liming materials is one of the most important management inputs in successful crop production and soil acidity amelioration. Consider some of the benefits of a sound liming program:

- Improved soil physical, chemical and biological properties.
- Improved symbiotic N fixation by legumes.
- Positively influence the availability of plant nutrients.
- Reduced toxicities to crops.
- Improved effectiveness of certain herbicides.
- Supply Ca, Mg and possibly other nutrients depending on their chemical composition.

The chemical availability of several nutrients such as P and S is improved by liming acid soils. Insoluble soil complexes of P and S are changed to more plant-available forms with the application of liming materials. Changes in soil pH affect the availability of the various plant nutrients differently. The availability of most nutrients is greatest in the soil pH range of 5.8 to 7.0.

Many research studies have shown the importance of applying appropriate amounts of lime on acidic soils for higher crop yields. **Table 1** summarizes results from some of these studies conducted around the world.

Choosing and Applying the Right Lime Source

Several factors should be carefully considered to have a successful program to apply lime to acid soils. Important factors include choosing an available and appropriate lime source, determining its rate and applying it under field conditions.

Source Factors

Chemical Form

The two major lime sources are calcitic lime and dolomitic

Abbreviations and Notes: N = nitrogen; P = phosphorus; S = sulfur; Ca = calcium; Mg = magnesium; Al = aluminum.

Table 1. Yield increases with lime application on acidic soils for different crops in different parts of the world.

Country	Crop	Yield increase with lime application, %	Citation	Observation
Argentina	Alfalfa	61	Gambaudo et al., 2001	
Brazil	Soybean	42	Oliveira and Pavan, 1996	No till; lime applied at the soil surface
Chile	Forage grasses	70	Alfaro et al., 1998	Average of three grass species
China	Cabbage	42	Lei et al., 2003	
China	Corn	59	Lei et al., 2003	
Ecuador	Pineapple	20	Mite and Medina, 2008	Optimum rate of 1.5 t/ha $CaCO_3$; higher rates induced root disease
Kenya	Corn	500%	Nekesa et al., 2005	Extremely acidic soil
Kenya	Beans	300%	Nekesa et al., 2005	Extremely acidic soil
Russia	Nine consecutive crops in rotation	As high as 32 (avg.=14)	Lukmanov et al., 2011	Lime applied once during crop rotation cycle
USA	Wheat	35	Beegle, 1996	
USA	Corn	500	Alley, 1996	
USA	Alfalfa	635	Alley, 1996	

lime. Calcitic lime is produced by mining and grinding $CaCO_3$ rock. When pure, it contains 40% Ca or 100% $CaCO_3$. It serves as the standard of comparison for neutralizing values of other liming materials. Dolomitic lime is produced from rock containing $CaMg(CO_3)_2$. When Mg is deficient in a soil, dolomitic lime should be the source of choice.

Particle Size Effectiveness (PSE)

The fineness of grind determines how rapidly the lime will react with soil and neutralize acidity, ranging generally from 60 to 100%. Such percentage represents how much of the lime will react in terms of neutralizing soil acidity in three months at ideal soil moisture content. Increased fineness of grind produces many more particles of lime to react with soil particles. Materials with lower PSE tend to have a higher residual effect, while those with higher PSE tend to react faster in the soil. Liming materials with lower PSE should be preferred in situations where a farmer wishes a longer residual effect (e.g., when introducing no-till or perennial crops in a farm). Liming materials with higher PSE should be preferred in situations where a farmer needs faster product reaction or when lime has to be applied on the soil surface (e.g., in established no-till systems or perennial crops).

Effective Calcium Carbonate Equivalent (ECCE)

The ECCE is a very important variable to be considered in calculations of rate to be applied. The ECCE or Relative Neutralizing Value combines two indexes (CCE and PSE) into one single value for the purpose of adjusting lime requirements under field conditions. ECCE is calculated as follow:

ECCE = (CCE x PSE)/100, where:

CCE = Calcium Carbonate Equivalent
PSE = Particle Size Effectiveness

with CCE and PSE obtained by laboratory analysis.

In practical terms the ECCE reflects how much of the lime, on a percent basis, will react in three months time as compared to finely-ground $CaCO_3$.

The lower the ECCE, the higher the rate of lime application should be to obtain the same effect in terms of soil acidity control. Formulas for calculating lime requirement are region-specific, but should always consider the ECCE. As an example, let's suppose that a laboratory's lime requirement for a material with 100% ECCE was 5.0 t/ha, but a farmer chooses a liming material with 80% ECCE. Thus, the farmer will need to apply (100 x 5.0/80) = 6.25 t/ha of the chosen liming material. In

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Lime application varies according to the farm scale, but its contribution to sustained productivity is critical regardless of the method of delivery.

IPNI 2012 TASII-1061

IPNI 2011 LPR04-1061

Deficiency symptoms for phosphorus in corn (*left*) and magnesium in soybean (*right*), which are two common issues on acidic soils.

case the farmer chooses a liming material with 110% ECCE, the lime application rate would be (100 x 5.0/110) = 4.54 t/ha.

Physical Form

Lime is available in several physical forms, the most common being crushed or ground rock. This is the form that is regularly used by growers under field conditions. Pelletized lime is produced by binding or compressing fine lime particles into larger granules or pellets. These larger particles are easier to spread and create less dust when handling. This makes pelletized lime quite popular under some situations (e.g., on home lawns and gardens). But pelletized lime is usually more expensive than conventional sources because of the added cost of pelletizing. Suspension lime is produced by suspending finely ground lime, up to 200-mesh, in water and applying with suspension fertilizer application equipment. Usually, it is applied at a rate of 225 to 450 kg (500 to 1,000 lbs) of a 50/50 water and finely ground lime mixture. The cost of suspension lime is also usually higher because of the additional cost of grinding the lime to the fine, 100- to 200-mesh size.

Rate Factors

Soil pH

As discussed earlier, soil pH identifies the degree or intensity of active acidity or alkalinity of the soil. It indicates the level of acidity a plant root will experience while growing in a specific soil. Used alone, however, it is not a good indicator of lime requirement.

Buffer Capacity

Lime requirement is related to soil pH and the buffer capacity or CEC of the soil. Buffer capacity reflects how strongly the soil resists a change in pH. Total amount of clay, type of clay, and the organic matter influences the buffer capacity. Sandy soils have low CECs and are weakly buffered, so they require less lime to raise the pH.

Crop to Be Grown

Some crops are more tolerant of soil acidity than others. Blueberries, potatoes and watermelons tend to be more acid- tolerant than crops like corn, soybeans, wheat, alfalfa, and clovers. As target pH for the crop to be grown increases, lime requirement increases.

Geographic Region

The types of clay present in soils can vary among geographic regions. Generally, humid regions have more highly weathered soils containing clays with low CEC. Soils in the less humid regions that have been exposed to less intense weathering processes, as well as those in the glaciated regions, tend to have clays with higher CECs. Areas of higher annual rainfall consequently may have a need for more frequent liming than semi-arid regions.

Applying Lime Under Field Conditions

Time and Frequency

Lime reacts with the soil only when water is available. Liming materials are however low in water solubility. Therefore, growers should apply lime to a soil as early as possible, before sowing a crop, as time and soil moisture can facilitate lime reaction and soil pH adjustment to the target crop. Two to three months before sowing a crop is usually the minimum length of time for good lime reaction. In case such a long time is not available, growers should plan on applying liming materials with a more rapid reaction in soil (e.g., CaO and $Ca(OH)_2$ or similar products can react with soil in two weeks time, if soil moisture is adequate). For forage and perennial crops, it is recommended to apply lime two months before the traditional period for extended rains starts. Liming acid soils is usually required every three to five years, depending on several factors like management, rainfall, soil characteristics, etc. Soils in areas of moderate to heavy rainfall patterns tend to become acid (or more acid) with time.

Placement and Soil Depth

Uniform application and thorough incorporation of lime in the soil are essential to a good liming program. Growers should choose the machinery and labor carefully for such an important operation. Experiments have shown that localizing lime is generally less effective than incorporating it in the whole field. In several specific situations, like in well-established no-till fields, perennial crops, pastures, hay meadows, lawn, and turf, incorporation of lime into the soil is not possible. In such cases local experiments should define the methodology for soil sampling and best possible placement.

In farms with heterogeneous soil pH areas, precision agriculture concepts and tools can help devise a sound lime application plan. This plan will include appropriate collection of soil samples, creation of maps, and variable-rate application of lime.

Lime recommendations are customarily made on the assumption that the liming material will be incorporated to the tillage depth represented by the sample submitted to the laboratory, which is most often 20 cm or 8 in. For cultivated crops and new pastures with depths of incorporation other than the regular 20 cm (deep tillage, no-till, etc.), the recommended rate of lime will need to be adjusted by multiplying the recommended rate with a factor calculated by dividing the real depth of incorporation by 20 cm.

Amount to Apply in Each Application

The maximum lime rate that is considered practical in a single application is about 10 t/ha (4.5 T/A). Recommendations in excess of this should probably be split into two separate applications. Splitting high recommendations into two applications, with separate incorporations, will help ensure that the lime is more uniformly distributed into the plant root zone by appropriate tillage.

Splitting the rate may also be necessary in cases where dolomitic lime is important (e.g., where Mg is also needed for crop development), but calcitic lime is available at a much lower cost in the region. In such a case, by splitting, it will be possible to apply dolomitic lime in at least one of the applications, adding Mg for crop development.

Other Practices Used for Soil Acidity Amelioration

Liming a soil is no doubt the best alternative to ameliorate surface soil acidity, which provides conditions for adequate crop development. No other practice is as efficient and economical as liming a soil. However, some other alternatives might be of use under specific situations for managing detrimental effects of soil acidity on crop growth.

Phosphogypsum or Gypsum Use

Chemically, gypsum ($CaSO_4 \cdot 2H_2O$) is a neutral salt with no direct effect on soil pH. However, many researchers have shown that phosphogypsum (PG), formed as a by-product of processing phosphate ore and sulfuric acid into phosphoric acid, can ameliorate subsoil acidity with positive influences on plant root development. This is especially important in rainfed cropping systems, where root absorption of water and nutrients may be limited, thereby affecting plant growth, if roots do not develop well and reach deeper soil layers.

The criteria to determine when to apply gypsum to ameliorate subsoil acidity should be based mainly on the amounts of soil exchangeable Ca and Al^{3+}, or sometimes soil clay content (determined from soil samples collected at 40 to 60 cm (15 to 24 in.) depth or beyond). Calcium lower than 5 $mmol_c/dm^3$ and/or Al^{3+} higher than 5 $mmol_c/dm^3$ indicates a good chance for a response to gypsum.

Soil clay content is used in some cases to recommend the rate of gypsum to apply. In Brazilian oxisols, where use of PG has become a routine practice, the amount to be applied is calculated by the following expression: PG = clay x 50

where, PG = amount of PG in t/ha and clay = clay content in % at 40 to 60 cm (16 to 24 in.) soil depth.

This formula has been extensively tested in Brazil with success. Other regions where PG is available will need to calibrate site-specific recommendations.

Cultivar Selection

The availability of toxic Al to plants is enhanced by low pH, and Al toxicity is a major factor limiting crop production on acid soils. Liming such a soil is a natural and logical practice to overcome soil acidity problems. However, in situations or regions where lime availability is low and/or the cost of lime is high, it might be useful to use a cultivar tolerant to soil acidity and especially tolerant to Al toxicity.

There is considerable variability in Al tolerance among plant species. This has been useful to breeders in developing Al-tolerant cultivars of various crops, as well as to researchers in studying the physiology and biochemistry of Al tolerance. Wheat has proven to be particularly useful in this respect, with up to 10-fold differences in Al tolerance among its different genotypes.

Thus, it is important to investigate in one's region if some local cultivars are available that are less susceptible to soil acidity and Al toxicity. In fact, using appropriate cultivars often leads to a higher degree of success in any liming program.

Information for this article was extracted from the new IPNI Publication entitled Soil Acidity Evaluation and Management. For more details on this publication please see http://info.ipni.net/SAEM or contact our circulation department at circulation@ipni.net.

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Economics of Fertilizer Application to Maize in North China

By Ping He, Jiagui Xie, Yuying Li, Yilun Wang, Liangliang Jia, Rongzong Cui, Hongting Wang, Yuehua Xing and Kegang Sun

Results from field trials conducted for three years in seven provinces in North China's maize production area showed that average yield responses to fertilizer N, P and K were 1.89, 0.95 and 0.97 t/ha, respectively. Economic returns with N and P fertilization increased with increase in yield responses and fertilizer prices, but those with K fertilization decreased with increase in K prices. Use of Nutrient Expert® led to higher grain yields and farmer profits.

As one of the most important crops used as food, forage, and a raw material for industry, maize plays an important role in food security. Ranked as the most widely planted crop in China, its planting area occupied 29.5% of the food crops in the country with 32.5 million ha in 2010 (China Agriculture Yearbook, 2011). Maize in China is mainly planted in the Northeast (Heilongjiang, Jilin and Liaoning) and North Central regions (Hebei, Henan, Shandong and Shanxi), which represents 61% of the total maize planting area in China.

Fertilizers play an important role in increasing food production and maintaining food security in China. However, their excessive and unbalanced use has become a common issue in China (He et al., 2009). Nutrient Expert® (NE), a new easy-to-use, interactive and computer-based nutrient decision support system developed by the International Plant Nutrition Institute (IPNI) to rapidly provide nutrient recommendations for an individual farmer field in the presence or absence of soil testing data, has proven to be a successful method in maintaining grain yields and increasing nutrient use efficiency (Chuan et al., 2013ab; Xu et al., 2013). However, due to the variability in yield responses, grain prices and fertilizer costs, it is also important to evaluate and compare the economics of fertilizer application in maize in China under different yield responses and price/cost scenarios. We conducted this study to determine: (1) yield responses to fertilizer N, P and K application, (2) economic returns from N, P and K fertilizers application, and (3) economic returns based on current and some anticipated yield response, fertilizer rate, crop price and fertilizer price scenarios in maize production areas in North China.

On-farm trials were conducted in Northeast and North Central China from 2010 to 2012 on 374 farms. Specifically, on-farm trials were conducted in Heilongjiang (43) Jilin (58), Liaoning (41), Hebei (49), Henan (112), Shandong (33), and Shanxi (37) provinces, respectively. Five treatments were laid out in every field trial with plot areas ranging between 40 and 90 m^2. Treatments included: (a) NE, where fertilizer application rates (kg/ha) ranged from 110 to 231 N, 31 to 89 P_2O_5, and 28 to 108 K_2O, respectively; (b) 0-N or N omission plot, where only P and K were applied; (c) 0-P or P omission plot, where only N and K were applied; (d) 0-K or K omission plot, where only N and P were applied; and (e) FP or farmers' fertilization practice, where fertilizer rates were determined and applied by farmers. Fertilizer rates (kg/ha) in FP treatments ranged from 48 to 460 N, 0 to 252 P_2O_5, and 0 to 177 K_2O, respectively, across different experimental farms. Fertilizer sources were urea, triple superphosphate or diammonium phosphate, and potassium chloride or potassium sulfate. Maize varieties were chosen by farmers and planting densities ranged from 55,000 to 75,000 plants/ha. Summer maize was irrigated only once during the whole growing period (i.e., after seeding), while spring maize was completely rainfed. Farmers did the weeding and pest/disease control. At maturity, grain yields were determined from a 20 to 50 m^2 harvest area and recorded at a standard moisture content of 15.5%.

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; 1US$ = 6 Yuan.

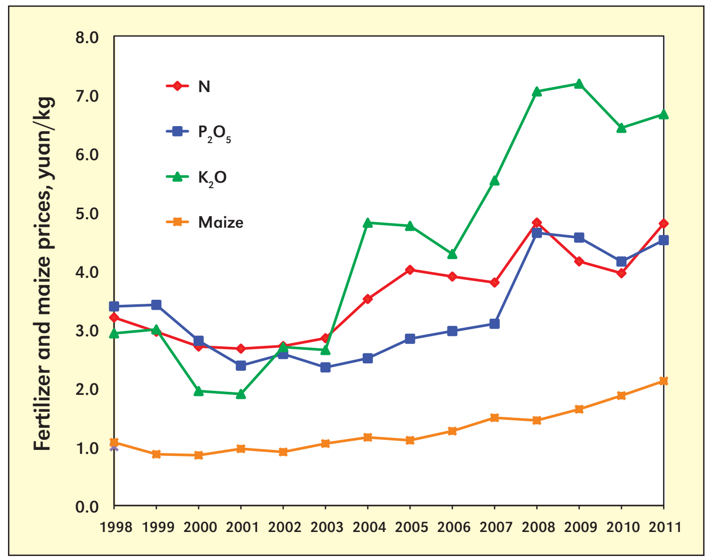

Figure 1. Variability in maize and fertilizer N, P and K prices in China since 1998.

Yield responses due to N, P and K fertilizers were calculated from yield differences between NE and different omission treatments. Economic returns, expressed as value to cost ratio (VCR, yuan/yuan), were calculated by first multiplying crop price and yield response and then dividing the value by costs of applied N, P and K fertilizers. We also estimated VCRs at three fertilizer price scenarios, viz., (a) current scenario, where we used the averaged price across 2010 to 2012, (b) 150% and (c) 200% of current prices at three different yield responses (with 25th, 50th, and 75th percentiles representing low, medium and high yield responses, respectively). The corresponding maize prices used were estimated based on corresponding relationships developed between maize price and fertilizer price with data from **Figure 1**. The following relationships were obtained between prices for maize (Y) and N, P and K fertilizers, respectively.

Field Validation of Nutrient Expert® for maize in Henan, China.

$$Y = 0.4385 \times e^{0.2945*N}\ (R^2=0.6531)$$
$$Y = 0.089 \times P^2 - 0.2713 \times P + 1.1426\ (R^2=0.5996)$$
$$Y = 0.678 \times 2e^{0.1339K}\ (R^2=0.802)$$

Yield Responses

Since yield responses to fertilizer N, P and K applications across seven different provinces did not differ much between NE and FP, only yield responses from NE plots are presented here. Averaged across seven provinces, yield with treatment NE was 10.1 t/ha, while yield losses of 1.89 (range 0.34 to 7.9), 0.95 (range 0.01 to 5.4) and 0.97 (range 0.01 to 4.1) t/ha occurred without N, P and K applications, respectively. Data indicated large variability in and high maize yield responses to N, P and K fertilization.

Economic Returns

Economic returns followed trends quite similar to yield responses. Data indicated that VCRs of N, P and K ranged between 0.5 to 12.1, 0.1 to 43.7, and 0 to 18.6, respectively. This suggested that on average for every yuan invested in fertilizer N, P and K, an additional maize value of 2.8, 7.8 and 4.6 was produced across 374 sites in seven provinces (**Figure 2**). Although yield responses followed as N > K > P, VCRs followed as P > K > N. Higher VCR values from P related well with lower P application rate (57 kg P_2O_5/ha) and lower P fertilizer prices compared with N and K fertilizer rates and prices. Although N response was almost twice the P response, higher N rate (three times the P rate) resulted in lower VCR for N fertilization. Among the 374 field trials, 30, 39 and 43 sites from N, P and K applications, respectively, had VCR<1.0, accounting for about 8, 10 and 11% of the total observation sites. This suggested that under current nutrient management practices and market situation, about 30% of the sites in North China have unfavorable economic returns from fertilizing maize.

Economic Returns Under Anticipated Price and Crop Response Scenarios

Values of VCR for N fertilization ranged from 4.3 to 12.3 for NE and 2.2 to 8.6 for FP treatments (**Table 1**). The VCR values in FP occupied 50 to 70% of those from NE for same

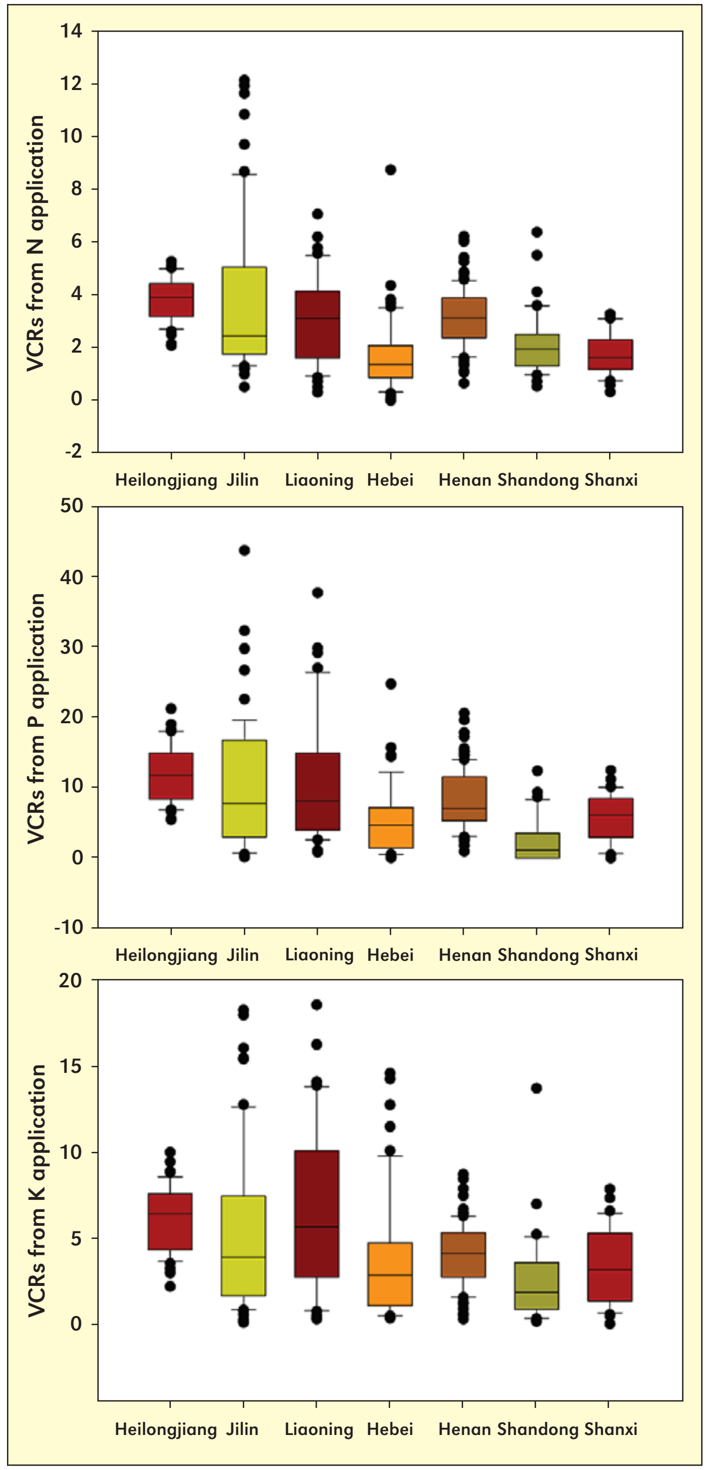

Figure 2. Variability in value to cost ratios (VCR) with N (top), P (middle) and K (bottom) fertilization in maize based on actual rates and prices of fertilizer and maize crop across seven provinces in North China. Fertilizer prices used were 3.96, 4.8 and 5.28 yuan/kg N, 4.16, 4.52 and 4.91 yuan/kg P_2O_5, and 6.43, 6.67 and 6.92 yuan/kg K_2O, and maize prices used were 1.87, 2.12 and 2.39 yuan/kg for 2010, 2011 and 2012. *Data source: China Agriculture Products and Profits Compilation.* Boxes represent data within the first and third quartiles (interquartile range). The thin line denotes the second quartile or median. Lines extending beyond the interquartile range denote the 10th to 90th percentile of the data. Statistical outliers are plotted as individual points outside these lines.

Table 1. Value to cost ratio for maize fertilization at different actual crop response levels (25th, 50th and 75th percentile) and fertilizer application rates under current and anticipated costs of fertilizers. North China.

	Nutrient Expert			Farmer Practice		
	25th*	50th	75th	25th	50th	75th
N response, kg/ha	1,076	1,748	2,537	937	1,652	2,347
N rate, kg/ha	110	150	190	190	220	250
Cost of N (4.8) and maize (2.12), yuan/kg**	4.3	5.1	5.9	2.2	3.3	4.1
Cost of N (7.2) and maize (4.02), yuan/kg	5.5	6.5	7.5	2.8	4.2	5.2
Cost of N (9.6) and maize (8.83), yuan/kg	9.0	10.7	12.3	4.5	6.9	8.6
P response, kg/ha	455	805	1301	381	714	1,163
P_2O_5 rate, kg/ha	50	60	70	80	100	120
Cost of P_2O_5 (4.5) and maize (2.12), yuan/kg	4.3	6.3	8.7	2.2	3.3	4.5
Cost of P_2O_5 (6.8) and maize (3.39), yuan/kg	4.6	6.7	9.3	2.4	3.6	4.8
Cost of P_2O_5 (9.0) and maize (5.96), yuan/kg	6.0	8.8	12.3	3.1	4.7	6.4
K response, kg/ha	403	835	1,328	381	759	1,234
K_2O rate, kg/ha	60	70	80	0	30	60
Cost of K_2O (6.7) and maize (2.12), yuan/kg	2.1	3.8	5.3	-	8.0	6.5
Cost of K_2O (10.0) and maize (2.59), yuan/kg	1.7	3.1	4.3	-	6.5	5.4
Cost of K_2O (13.3) and maize (4.05), yuan/kg	2.0	3.6	5.0	-	7.7	6.2

*25th, 50th and 75th denote respective percentiles.
**Fertilizer prices chosen were current, 150%, and 200% of the current prices, and maize prices were calculated from the correlation equations given in the text.

class of yield responses. The higher VCR values in NE were due to the higher yield responses and optimized lower N application rates. The values of VCR increased with increase in both yield responses and N fertilizer prices. These results clearly show that N is being over applied to most maize fields in China.

Values of VCR for P fertilization ranged from 4.3 to 12.3 for NE and 2.2 to 6.4 for FP treatments (**Table 1**). The VCR values with P fertilization in NE were more than two times that in FP treatment for same class of yield responses and for similar reasons (higher yield responses and optimized lower P application rates). Again, the VCR values increased with both yield responses and P fertilizer prices. Interestingly, the VCR values from 75th percentile yield responses in FP achieved comparable VCR values from the 25th percentile yield responses in NE. Like N, the data on VCR for P clearly indicates that P fertilizer is being over applied to maize in China.

The VCR values for K fertilization were quite different from those of N and P (**Table 1**). In the 25th percentile, no K fertilizer was applied in FP, so no observations for VCR occurred under this scenario. Although higher VCRs were achieved by FP with less K fertilizer input, NE-based K application with right rates could still obtain favorable VCRs over 1.7. Unlike with N or P fertilization, VCR values decreased with increase in K fertilizer prices, and the 75th percentile yield response could not achieve a better VCR than 50th percentile yield response due to 50 kg/ha more K_2O input. This was probably because the increase in maize price could not keep up with the rapid increase in the price of potash (**Figure 1**).

The above results and discussion on VCRs were merely from the applications of N, P and K under different scenarios. However, based on the actual yield and profitability scenario observed across 374 observations, NE was able to achieve a grain yield of 10.3 t/ha and a net profitability of 18,903 yuan/ha with 157-56-67 kg N-P_2O_5-K_2O/ha input, while FP achieved a grain yield of 9.99 t/ha and a net profitability of 18,154 yuan/ha with 225-61-47 kg N-P_2O_5-K_2O/ha input. The net increase in profitability of NE over FP was 748 yuan/ha, of which one-third was from fertilizer saving and two-thirds was from the increase in grain yield. It is not a big profit under the current smallholding situation, but is a considerable number under large scale farming system in the near future.

Summary

Maize yield responses to N, P and K fertilization were highly variable across different provinces in China. Average yield responses to fertilizer N, P and K were 1.9, 0.95 and 0.97 t/ha across seven provinces. The VCRs for fertilizer N, P and K ranged between 0.5 to 12.1, 0.1 to 43.7, and 0 to 18.6, respectively. Omission of N, P and/or K resulted in losses of both yield and profitability. Economic returns from N and P fertilization increased with increase in yield responses and fertilizer prices, but those from K fertilization decreased with increase in K prices. All of the VCRs were higher than 2.0 when yield responses were over the 25th percentile for N and P fertilizers, and those for NEs were much higher than FP. Although profitability in the FP treatment with less K input was higher than in NE treatment under K application, the optimized Nutrient Expert®-based fertilizer recommendation proved to be a successful nutrient decision support tool leading to higher grain yield and profitability. BC

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Fertilizer Management of Highland Banana in East Africa

By Kenneth Nyombi

East African highland bananas showed substantial yield increases with balanced fertilizer application. However, very high fertilizer cost and low banana market value in the region resulted in only small returns on investment. This poses a challenge to fertilizer use in remote areas in Uganda at this time.

East Africa highland banana (*Musa* spp., AAA-EAHB) or 'matooke' is a major staple crop grown for food and sale by smallholder farmers in Uganda. Banana yields in farmers' fields average 15 t/ha fresh weight (FW), and have remained small compared with yields of 60 to 70 t/ha/yr achieved at a research station with fertilizer application (Tushemereirwe et al., 2001; Smithson et al., 2001). Low banana yields achieved by smallholder farmers are attributed to poor soil fertility, low fertilizer use and increasing pest pressure (especially the banana weevil - *Cosmopolites sordidus*) and moisture stress (NARO, 2000). Very few (<5%) banana farmers in Uganda use mineral fertilizers due to perceived high cost, poor availability, and lack of knowledge related to its use. Past research has highlighted the large extent of soil fertility decline. For most soils in Uganda, soil pH, extractable P, Ca and K are below critical concentrations for most crops (Ssali, 2002). Increased agricultural productivity, mainly through increased fertilizer use, is recognized as key to alleviating poverty and ensuring food security in rural parts of Uganda. To increase banana productivity in a profitable way, there is a need to develop fertilizer recommendations for balanced application of nutrients.

Two nutrient omission trials were established at Kawanda (near Kampala) in central Uganda and Ntungamo in southwest Uganda to: (i) identify limiting nutrients and nutrient interactions in banana production; (ii) quantify banana yield responses to mineral fertilizers; and (iii) assess agronomic and economic efficiency of fertilizer use in banana production. Soils at Kawanda are Haplic Ferralsols, while soils at Ntungamo are Lixic Ferralsols. Soil pH was 5.5 at Kawanda and 4.8 at Ntungamo. Average soil organic matter and total N values were higher at Kawanda (2.6 and 0.1%, respectively) than at Ntungamo (0.7 and 0.07%, respectively). Average Mehlich-3 extractable P was higher at Ntungamo (3.5 mg/kg), but exchangeable K and Mg were low at both sites. Rainfall at both sites averages 1,258 mm/yr and follows a bimodal pattern with dry periods from June to July and January to March.

The trials were laid out in a completely randomized block design with four replicates. Treatments consisted of the following nutrient applications (kg/ha/yr): (1) 0N-0P-0K; (2) 0N-50P-600K; (3) 150N-50P-600K; (4) 400N-0P-600K; (5) 400N-50P-0K; (6) 400N-50P-250K, and (7) 400N-50P-600K. With the exception of the control, all plots received 60Mg-6Zn-0.5Mo-1B kg/ha/yr. Nitrogen and K were applied in 8 splits each year, while P, Mg, Zn, Mo and B were applied in two splits at the start of each rainy season. All fertilizers were applied in a circle at 0.4 to 0.5 m from the base of the plant. A plant spacing of 3 x 3 m was used resulting in a density of 1,111 plants/ha.

Abbreviations and notes: N = Nitrogen; P = phosphorus; K = potassium; Ca = calcium; Mg = magnesium; B = boron; Mo = molybdenum; Zn = zinc.

Under good management planting, one banana corm results in 3 production cycles. Yields from crop cycles 2 and 3 better represent a stable state. The development rate for banana at Kawanda was faster than at Ntungamo probably because of the difference in average temperatures (22 vs. 20°C, respectively). It was assumed that cycle 3 at Kawanda is reaching a stable state and would be comparable with cycle 2 from Ntungamo. The nutrient conversion efficiencies [CE; kg finger (dry matter)/kg nutrient in plant] for individual banana plants at harvest were calculated. Bunch yields (t/ha/yr) were calculated based on the duration from planting to harvest, but yields of successive crop cycles were based on the duration between consecutive harvests.

Banana Yields

Bunch yields (t/ha/yr) differed significantly among fertilizer treatments and sites ($p = 0.001$) (**Table 1**). Maximum bunch yield increases over the control plot yields were 7.2 t/ha/yr at Kawanda and 29.5 t/ha/yr at Ntungamo. Poor yields observed in control plots at both sites can be attributed to poor soil fertility. Potassium applications increased bunch yields, particularly at Ntungamo, where the soil K level of 0.09 $cmol_c$/kg was far below the critical value of 0.2 $cmol_c$/kg. Attainable yields and yield increases with fertilizer were smaller at Kawanda than at Ntungamo (**Table 1**) due to low available soil water and clay

Table 1. Yields of East africa highland banana as affected by mineral fertilizer application at Kawanda and Mbarara, Uganda.

	Bunch yield, t/ha/yr				
	Kawanda			Ntungamo	
	C1*	C2*	C3*	C1	C2
0N-0P-0K	5.4	18.2	15.3	2.1	13.7
0N-50P-600K	7.6	25.4	22.9	7.6	33.8
150N-50P-600K	6.1	19.2	22.4	8.9	39.6
400N-0P-600K	5.9	23.7	26.5	7.4	27.9
400N-50P-0K	5.7	19.7	18.9	2.6	13.0
400N-50P-250K	5.5	22.9	22.2	7.9	36.4
400N-50P-600K	5.7	22.1	22.5	9.1	43.2
Mean	6.0	21.6	21.5	6.5	29.7
S.E.D.**	0.4	1.63	1.63	0.5	2.53

*C1, C2 and C3 denote banana crop cycles 1, 2 and 3, respectively.
**S.E.D. denotes standard error of difference.

Potassium deficiency in banana plants supplied with N, P and micronutrients at Ntungamo, south-western Uganda.

Balanced banana nutrition - A trial plot well supplied with N, P, K, Mg and other micronutrients at Ntungamo, south-western Uganda. Note the mat management, i.e., a mother plant (C1), daughter (C2) and grand daughter (C3).

accumulation in the B-horizon, which limits root exploration of this soil layer. The larger yield responses to added fertilizer at Ntungamo can be explained by the coarser soil texture and lower bulk density, resulting in better root distribution (data not published) and improved soil moisture availability.

The N, P and K yield gaps at Ntungamo for cycle 2 plants were 9.4, 15.4 and 30.2 t/ha/yr, respectively, indicating that K was the most limiting nutrient followed by P and N. Increasing fertilizer N application rate from 150 to 400 kg/ha/yr resulted in a small yield increase (3.6 t/ha/yr), while increasing fertilizer K rate from 250 to 600 kg/ha/yr resulted in a yield increase of 6.8 t/ha/yr. In Uganda, the official mineral fertilizer reccomendation (kg/ha/yr) for banana is 100N-30P-100K-25Mg. From our experimental results, it is clear that the amount of K in the official reccomendation should be raised to at least 200 kg/ha/yr. Information from this work can be used to develop specific multi-nutrient fertilizers for banana, which are currently not avialable.

Total Nutrient Uptake and Apparent Fertilizer Recovery Efficiency

Total N, P and K uptake values determined at the time of harvest were significantly different ($p = 0.001$) among fertilizer treatments and sites. Average nutrient uptakes were greater at Ntungamo than at Kawanda, with averages of 113 vs. 74 kg N/ha, 13.2 vs. 8.8 kg P/ha, 353 vs. 280 kg K/ha (**Table 2**). The apparent fertilizer recovery efficiencies for N (<10%) and P (<5%) calculated in this study were small. Larger K recovery efficiencies (36 to 49%) at both trial sites indicate the importance of K nutrition in banana growth. However under intensive management in south America (Costa Rica and Honduras), maximum recovery efficiencies are estimated at 50% N, 30% P and 75% K (Lopez and Espinosa, 2000).

Table 2. Average N, P and K uptake (kg/ha) for banana (crop cycles 1, 2 and 3) at the harvest stage of cycle 1 and recovery efficiency for highland banana plants at harvest stage at Kawanda and Ntungamo.

	-------- Kawanda --------			-------- Ntungamo --------		
Treatment/site	N	P	K	N	P	K
0N-0P-0K	70.5	7.40	204	62.6	6.70	121
0N-50P-600K	78.3	9.50	332	111	13.2	420
150N-50P-600K	79.6	9.20	316	138	17.3	487
400N-0P-600K	74.7	8.90	303	121	13.9	415
400N-50P-0K	66.2	8.30	237	73.5	7.90	147
400N-50P-250K	70.9	8.50	256	136	15.7	367
400N-50P-600K	78.9	9.70	312	149	17.6	510
Mean	74.2	8.80	280	113	13.2	353
S.E.D.	3.67	0.43	15.5	6.90	0.85	21.1
Fertililizer recovery efficiency, %	2	1	14	10	5	49

*S.E.D. denotes standard error of difference.

Profitability of Fertilizer Use

Since banana is a perennial crop, with yields increasing with sucessive harvests to a stable state, yields (t/ha/yr) for cycle 3 plants at Kawanda and cycle 2 plants at Ntungamo were used to calculate the profitability of fertilizer use.

Application of fertilizer at rates targeting high yields without improved soil moisture management (e.g., mulching) at Kawanda in central Uganda resulted in mostly negative gross margins. This was due to the small yield response to fertilizer application. At Ntungamo, fertilizer use was profitable, with highest gross margins of about US$1,000/ha with moderate rates of N and P application and high rates of K application (**Table 3**). However, very high fertilizer costs and low banana market value at these sites, because of poor access to major banana markets in Uganda, meant that the added economic benefits over control plots were low or negative. To make fertilizer use attractive among smallholder banana farmers in central Uganda, agronomic efficiency of the applied fertilizer has to be increased. Supporting farmers access to markets that offer higher prices for banana will be crucial to ensure profitable banan production intensifi-

Table 3. Profitability of fertilizer use in two nutrient ommission trials calculated for cycle 3 plants at Kawanda and cycle 2 plants at Ntungamo.

	Kawanda				Ntungamo			
Treatment	Yield–C3, t/ha/yr	Fertilizer cost, US$/ha/yr	Profits*, US$/ha/yr	Benefit over control, US$/ha/yr	Yield–C2, t/ha/yr	Fertilizer cost, US$/ha/yr	Profits, US$/ha/yr	Benefit over control, US$/ha/yr
0N-0P-0K	15.3	0	1,101	-	13.7	0	986	-
0N-50P-600K	22.9	1,616	32	-1,069	33.8	1,616	817	-169
150N-50P-600K	22.4	1,847	-234	-1,335	39.6	1,847	1,003	17
400N-0P-600K	26.5	1,992	-84	-1,185	27.9	1,992	16	-970
400N-50P-0K	18.9	1,349	11	-1,090	13.0	1,349	-413	-1,399
400N-50P-250K	22.2	1,716	-118	-1,219	36.4	1,716	904	-82
400N-50P-600K	22.5	2,231	-611	-1,712	43.2	2,231	878	-108

*Profits were calculated using the farm gate price of US$72/t (fresh weight) of banana and costs in US$ of 1 kg Urea = 0.7; 1 kg MOP = 0.76; 1 kg TSP = 0.95; 1 kg magnesium sulphate = 0.48; 1 kg of zinc sulphate = 3.34; 1 kg of borax = 19 and 1 kg of sodium molybdate = 71.
1US$ = 2,090 Ugandan Shillings. Labor and transport to Ntungamo costs were not included in the calculations.

cation. Encouraging practices that increase soil organic matter and soil moisture availability, such as mulching, improve fertilizer recovery in banana production systems (McIntyre et al., 2000). Use of fertilizer rates targeted at maximizing economic benefits may also provide an entry point to support smallholder farmers to intensify banana production in Uganda.

Summary

Results from nutrient omission trials in Uganda showed that K was the most limiting nutrient for banana growth. Drought stress played an important role in crop response to fertilizer input and affected sink filling, especially at Kawanda. Fertilizer recovery efficiencies measured in this study were low, far below the values published for bananas in Latin America, particularly for N and P. Profitable fertilizer use depends largely on fertilizer treatments and site conditions, with the highest gross margins obtained in well-drained soils. However, the results of this study showed that the economic benefit from fertilizer use was low because of high fertilizer cost and low market price for bananas. BC

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This paper has been adapted from an earlier publication: K. Nyombi, P.J.A. van Asten, M. Corbeels, G. Taulya, P.A. Leffelaar and K.E. Giller, 2009. Mineral fertilizer response and nutrient use efficiencies of East African highland banana (Musa spp., AAA-EAHB, cv. Kisansa). Field Crops Res. 117, 38-50.

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Friend of Fertilizer

In the December 2013 Issue of "*WIRED*" magazine, guest editor Bill Gates wrote:

I am a little obsessed with fertilizer. I mean I'm fascinated with its role, not with using it. I go to meetings where it's a serious topic of conversation. I read books about its benefits and the problems with overusing it … like anyone with a mild obsession, I think mine is entirely justified. Two out of every five people on Earth today owe their lives to the higher outputs that fertilizer has made possible.

It was refreshing to see someone of Bill Gates stature and fame make such a positive and supportive statement about fertilizer. His editorial was focused on innovation and how he is trying to advance innovation that improves people's lives the way fertilizer did as it helped fuel the Green Revolution.

Famous people have tremendous influence. Think back to the late 1980s when we had the great apple scare and a public campaign to ban Alar, a compound that was sometimes sprayed on apple trees before apples formed, to reduce early drop and extend the harvest season. A well-known actress acted together with the Natural Resources Defense Council (NRDC), a self-appointed environmental activist group, in a public affairs campaign to get EPA to ban Alar. CBS's *60 Minutes* aired a segment highlighting an NRDC report about the problems with Alar and the manufacturer ended up voluntarily withdrawing Alar from the market before a ban took effect, but not before the public became so scared that apples were taken out school programs and people were afraid to give their kids apple juice. Farmers went bankrupt and untold damage was done to the apple industry. It turns out there was no scientific proof that Alar was a problem … the whole campaign was based on propaganda rather than facts.

I am grateful for Bill Gates making a public statement about fertilizers after having studied the issues associate with them.

Terry L. Roberts
President, IPNI

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