BETTER CROPS

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2015 Number 4

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IPNI 2015 Soil Test Summary Preview



Phosphorus Management for Potatoes



Phosphorus and Cereals: The Role of Rotation



Also: The 2015 IPNI Scholars Announced! ...and much more



4Rs for Efficient Phosphorus Management in Kenya



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Our cover: Signs of phosphorus deficiency in maize, Western Kenya Photo by: S. Njoroge Editor: Gavin D. Sulewski Assistant Editor: Sharon Jollay Circulation Manager: Wendy Hollifield Design: Rob LeMaster Back page illustration: Greg Cravens INTERNATIONAL PLANT NUTRITION INSTITUTE (IPNI) Mostafa Terrab, Chairman (OCP Group) Oleg Petrov, Vice Chairman (Uralkali) Tony Will, Finance Committee Chair (CF Industries) HEADQUARTERS-Peachtree Corners, Georgia, U.S. T.L. Roberts, President S.J. Couch, Vice President, Administration B.L. Mikkelsen, Vice President, Communications B. Green, IT Manager B. Rose, Statistics/Accounting C. Smith, Administrative Assistant A. Williams, Communications Specialist Nitrogen Program C.S. Snyder, Conway, Arkansas, U.S. Phosphorus Program T.W. Bruulsema, Guelph, Ontario, Canada ASIA /AFRICA AND MID. EAST GROUP-Saskatoon, Saskatchewan, Canada A.M. Johnston, Vice President L.M. Doell, Corporate Secretary and Administrative Assistant China Program P. He, Beijing S. Li, Beijing F. Chen, Wuhan, Hubei S. Tu, Chengdu, Sichuan South Asia Program K. Majumdar, Gurgaon, Haryana, India T. Satyanarayana, Secunderabad, Telangana, India S. Dutta, Kolkata, West Bengal, India Southeast Asia Program T. Oberthür, Penang, Malaysia North Africa Program M. El Gharous, Settat, Morocco H. Boulal, Settat, Morocco Sub-Saharan Africa Program S. Zingore, Nairobi, Kenya Middle East Program M. Rusan, Irbid, Jordan AMERICAS AND OCEANIA GROUP—Brookings, South Dakota, U.S. P.E. Fixen, Senior Vice President, and Director of Research P. Pates, Administrative Assistant North American Program T.L. Jensen, Saskatoon, Saskatchewan, Canada R.L. Mikkelsen, Merced, California, U.S. T.S. Murrell, West Lafayette, Indiana, U.S. S.B. Phillips, Owens Cross Roads, Alabama, U.S. W.M. Stewart, San Antonio, Texas, U.S. Brazil Program L.I. Prochnow, Piracicaba, São Paulo V. Casarin, Piracicaba, São Paulo E. Francisco, Rondonópolis, Mato Grosso Northern Latin America Program R. Jaramillo, Quito, Ecuador Mexico and Central America Program A.S. Tasistro, Peachtree Corners, Georgia, U.S. Latin America-Southern Cone Program F.O. Garcia, Buenos Aires, Argentina Australia and New Zealand Program R. Norton, Horsham, Victoria, Australia E. EUROPE AND C. ASIA GROUP-Moscow, Russia S. Ivanova, Vice President V. Nosov, Krasnodar, Russia BETTER CROPS WITH PLANT FOOD (ISSN:0006-0089) is published quarterly by the International Plant Nutrition Institute (IPNI). Periodicals postage paid at Peachtree Corners, GA, and at ad-ditional 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, Peachtree Corners, GA 30092-2844. Phone (770) 447-0335; fax (770) 448-0439. Website: www.ipni.net. Copyright 2015 by International Plant Nutrition Institute.

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IPNI Scholar Award Recipients - 2015

he International Plant Nutrition Institute (IPNI) has selected the winners of the annual Scholar Award Program. A total of 37 graduate students, representing 13 countries, were chosen in 2015. Each winner receives the equivalent of US\$2,000.

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Mr. Zachary Stewart, University of Nebraska-Lincoln, Lincoln, Nebraska, USA. Ph.D. Program: Evaluating the Effect of Foliar Micronutrients on Maize Grain Yield, Grain Biofortification, and the Uptake, Mobility, and Partitioning of the Applied Micronutrients.

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Ms. Patricia Barreto, University of the Republic, Montevideo, Uruguay. Ph.D. Program: Quantification and Modeling of Nutrient Loss in Runoff for Different Combinations of Rotations and Soil Management in Uruguay.

Ms. Victoria Cerecetto, University of the Republic, Montevideo, Uruguay. M.Sc. Program: Microorganisms that Act on Phosphorus Phytoavailability: Detection of Mechanisms Involved, and Potential Use as Biofertilizers.

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Graduate students attending a degree-granting institution located in any country within an IPNI regional program are eligible. The award is available to graduate students in science programs relevant to plant nutrition science and the management of crop nutrients including: agronomy, horticulture, ecology, soil fertility, soil chemistry, crop physiology, environmental science, and others.

Regional committees of IPNI scientific staff select the recipients of the IPNI Scholar Award. The awards are presented directly to the students at a preferred location and no specific duties are required of them.

Funding for the scholar award program is provided through support of IPNI member companies, primary producers of nitrogen, phosphate, potash, and other fertilizers.

More information is available from IPNI staff, individual universities, or from the IPNI website: www.ipni.net/awards.

7th International Nitrogen Conference (INI 2016)

The Victorian Government and University of Melbourne are jointly hosting the 7th International Nitrogen Initiative Conference, at the Melbourne Cricket Ground, on December 4 to 8, 2016.

The theme of INI 2016 is **Solutions to Improve Nitrogen Use Efficiency for the World**. The program includes plenary presentations from many of the world's experts in the fields of nitrogen cycling and management, crop and animal production, emissions and environmental impacts with participation from research, industry and policy organizations globally. Further details of the conference are available at ini2016.com. THE CALL FOR PAPERS IS NOW OPEN



4R Practices for Efficient Phosphorus Management in Western Kenya

By Samuel Njoroge and Shamie Zingore

On-farm research evaluating 4R Nutrient Stewardship found source, rate, timing, and placement of P fertilizers can be managed to increase productivity, profitability and P use efficiency for smallholder farmers.



Severe phosphorus deficiency in maize grown in Siaya County, Western Kenya.

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Abbreviations and notes: P = phosphorus; Ca = calcium; SSA = sub-Saharan Africa; ppm = parts per million.

(maize P response >1 t/ha) increased from 35 to 83% over four cropping seasons (Table 1), illustrating the high susceptibil-

Table 1. Changes in phosphorus agronomic efficiency (PAE) and grain yield response to P over four seasons in P omis- sion trials* (Western Kenya, 2013-2014; IPNI SSA).						
Season	PAE**, kg grain/kg P	P response, t/ha	Sites with >1 t/ha response, %			
Long rain season 2013	11	0.46	35			
Short rain season 2013	32	1.30	58			
Long rain season 2014	50	2.06	78			
Short rain season 2014	48	1.96	83			
*26 on-farm trials were established in each season						

**PAE for each farm calculated as the yield difference (NPK - NK) / 40 kg fertilizer P. Average values for each season were calculated.

ity of P depletion when P application is omitted. A simplified, but effective approach towards the management of available P resources is required in order to sustainably increase crop productivity and attempt to replenish soil P in this region.

The 4R Nutrient Stewardship approach offers a strategy for identifying management practices that can help smallholder farmers in SSA improve P use efficiency (PUE) by optimizing the use of P resources available to them, leading to increased crop productivity and soil P status. Assessment of the various P sources available in the region and the factors that influence their effectiveness and profitability (i.e., rate, timing of application, and placement) offers a good starting point for equipping smallholder farmers and other agricultural stakeholders with the necessary knowledge for addressing P deficiency in crops.

P Sources and Their Relevance in SSA

The main P sources available to smallholder farmers in SSA are mineral P fertilizers such as diammonium phosphate (DAP) and triple superphosphate (TSP), phosphate rock (PR) such as Minjingu phosphate rock (MPR) in Tanzania and Telemsi phosphate rock (TPR) in Mali, and organic sources such as farmyard and cattle manure. However, fertilizer and PR sources are more effective at addressing P deficiency due to their higher P concentrations compared to any organic resources. While mineral fertilizers offer one of the most effective sources of soluble P, limited capacity of farmers to purchase fertilizer is a major hindrance to their increased use. Investments in inland infrastructure and subsidy programs such as those launched by various governments in the region could help in bringing down the costs of mineral fertilizers making them more attractive P sources.

The effectiveness of PR is mainly limited by varying P concentration, reactivity and solubility. As such, only a few PR sources, such as MPR and TPR, have been found to be suitable for direct application due to their relatively high P concentration and reactivity. Assessment of research data indicates that MPR compares favorably with TSP when applied at equal rates (**Figure 1**). Further studies on the economic benefits of MPR



Figure 1. Effects of phosphate rock (PR) and triple superphosphate (TSP) sources applied at equal total P rates on maize grain yield in western Kenya (Jama and Kiwia, 2009).

and TSP have indicated that MPR offers almost similar benefits to those of TSP (Jama and Kiwia, 2009). Given the high vulnerability for price changes in imported fertilizers, and the local availability of MPR, MPR is an attractive source of P given improved inland transportation. However compared to fertilizer P, PR require targeting to soil conditions that can enhance their solubility and ensure improved PUE. For example, MPR can serve as an effective P source in high P-fixing, acidic soils such as those of western Kenya. Acid soils are more conducive to PR dissolution than Ca-rich alkaline soils. Other options that can improve the PUE of PR are grinding to speed dissolution and agronomic effectiveness, and targeting the use of PR to specific crops and regions. For example, some legume crops excrete organic acids from their roots that facilitate P solubilization. Highly reactive PR is better targeted to fast growing crops with rapid P uptake demand; while less reactive PR is better suited to perennial crops, pastures and trees. Consideration of the economics of PR availability and access is a practical concern. For example, where lower grade PR that is easy to mine and modify occurs close to P-deficient soil, it can serve as a suitable source of P due to reduced acquisition costs.

Right P Rate in Smallholder Farming Systems

For crop production to increase sustainably, the right P application rate should aim at not only increasing crop yields, but also maintaining a positive soil P balance to avoid long-term depletion. In western Kenya, Nziguheba et al., 2002 showed that while maize responded to seasonal addition of 10 kg P/ ha, the desired positive soil P balances were only achieved at application rates greater than 25 kg P/ha (**Table 2**).

Table 2. Cumulative soil P balances* over five consecutive cropping seasons from the seasonal addition of differentrates of P fertilizers to a P-deficient soil in westernKenya (Nziguheba et al. 2002).							
	Season	Season	Season	Season	Season		
Application rate, kg P/	n ' 'ha		kg/ha	4	J		
0	-5	-9	-12	-24	-25		
10	4	7	11	2	8		
25	17	24	51	53	71		
50	41	83	122	146	188		
150	137	276	415	536	678		
*P applied	*P applied - P removed in grain + straw.						

The right P rate depends on: i) the source of P, ii) the soil P status, iii) the crop (or crops) to be grown, iv) the frequency of application, and v) the P-fixing capacity of a soil. Where P application is from slower P-releasing sources such as PR, higher rates may be required compared to more soluble sources. Soils with low P status will also require higher P rates compared to high P status soils, while single P applications, and applications in high P-fixing soils, will require higher P rates compared to seasonal P applications and application in low P-fixing soils, respectively. With regard to maize, one of the most important cereal crops in the region, data from P rate trials using TSP indicates minimal grain yield increase and income benefit for P rates higher than 40 kg P/ha (Figure 2). This is in line with data from a recent review of P studies (80% spot application and 20% broadcast) by Kihara and Njoroge, (2013). They recommended seasonal P application rates between 20 to 38 kg P/ha for high P-fixing soils, such as those in western Kenya, to ensure a marginal rate of return to P application of at least 100%.

Right Time of P Application

For sustainable crop production increases, timing P application is influenced by both the right time to apply P during a single cropping season as well as over several cropping seasons (e.g., seasonal versus annual application for the two crops per year that is common for western Kenya). The right time of P application is influenced by the P source, soil chemical and physical characteristics, and the amount of P to be applied. For soluble P fertilizers and PR of high reactivity, the right time for application is at planting, while less reactive PR should be applied well in advance of planting to allow time for dissolution. Where the P application rate is high, a single application can span a number of seasons, while for lower application rates, seasonal applications are necessary for both soluble fertilizers and PR. However, for high P-fixing soils, seasonal P applications at lower rates are preferable compared to single, high application rates (Buresh et al., 1997).

Right Placement of P

Under the low P input systems characteristic of smallholder farming in SSA, the right placement of applied P can drastically increase PUE, and yields. Spot placement of P fertilizers (which involves the placement of fertilizer in close proximity to seeds in each planting hole) results in higher PUE compared to broadcast application and incorporation. Studies have reported that spot fertilizer placement resulted in higher maize yields than broadcasting and incorporation at P rates less than 50 kg P/ha (van der Eijk et al., 2006). This implies that for the resource-scarce smallholder farmers, spot application of small amounts of P offers the best placement option for improving PUE.

Other Considerations for Improving the PUE

Apart from improving source, rate, time, and place practices in P management, there are other practices that smallholder farmers in SSA can use to improve the PUE of applied P. One of these is ensuring balanced nutrient application, as the response to P in both legume and cereal crops are often limited by multiple nutrient deficiencies. A review of P stud-





ies in P-fixing soils in western Kenya by Kihara and Njoroge (2013) reported that the lack of N application together with P decreased phosphorus agronomic efficiency (PAE) from 29 down to 19 kg grain/kg P. Given the low mobility of P in the soil, and the relatively high residual effect compared to other nutrients, smallholder farmers can also benefit from strategic rotation of legumes and cereals. In such a system, P application can be applied once every three seasons, compared to seasonally in continuous cereal cropping, thereby helping farmers save on scarce P resources.

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Crop Nutrient Deficiency Photo Contest Entries Due December 9, 2015

This year, the deadline for submitting entries to the annual IPNI contest for photos showing nutrient deficiencies is early December. Remember, our **Feature Crop** category for 2015 is **Root and Tuber Crops** (e.g., Potato, Sweet Potato, Cassava, Carrot, Beets, etc).

Our prizes are as follows:

- US\$300 First Prize and US\$200 Second Prize for Best Feature Crop Photo.
- US\$150 First Prize and US\$100 Second Prize within each of the N, P, K and Other Nutrient categories.
- Note that all winners are eligible to receive the most recent copy of our USB Image Collection. For details on the collection please see http://ipni.info/nutrientimagecollection

Entries can only be submitted electronically to the contest website: www.ipni.net/ photocontest. Winners will be notified and announced in early 2016. Look for results posted on ipni.net.



Iron deficiency in cassava.

Phosphorus Management for Potatoes

By Robert Mikkelsen

Economic rates of P fertilization are higher for potatoes than for many other crops due to shallow roots and sparse root hairs.BMPs are outlined to minimize the risk of P losses from potato fields.

Potatoes are the most important root and tuber crop for humans, and a significant economic crop for many farmers. More than a billion people consume potatoes each day. For example, a typical American consumes over 60 kg (140 lb) of potatoes each year (fresh and processed), far more than any other vegetable. Potatoes are currently grown in more than 125 countries, with China and India leading in production.

Proper management of P for potato production is a critical aspect to success. Potatoes have a relatively high P demand and a root system that is not particularly well suited to P uptake. This topic was the subject of a special symposium that was recently published in the American Journal of Potato Research. This article summarizes some of their key conclusions. Readers should refer to the symposium proceedings for additional information and specific scientific references.

Potato Root Development

The essential role of P for plants is well known, but special attention is given to potatoes due to their relatively low P recovery and efficiency. Potatoes have a rather low total requirement for P (25 to 45 kg P/ha), but a high requirement for available P in the soil, indicating low uptake efficiency. Potatoes are also somewhat inefficient in taking up other nutrients. For example, potatoes require 6 to 9 times more available K in the soil to reach 90% of their yield potential than crops such as wheat or sugar beet.

Potatoes have a relatively shallow root system, with the majority of the roots found in the upper 30 cm (14 in.) of soil. Potato roots generally stop development between 60 to 90 days after planting, linked closely with the maturation of the crop canopy and the end of new leaf development. As the plants divert resources to tuber bulking, root systems begin to deteriorate, although the nutrient uptake requirement is still relatively high.

Potatoes have a relatively low total root length density (about one-fourth of that of wheat), and also have relatively few of the root hairs that are critical for P uptake. Root hairs account for 21% of the total potato root mass, compared with 30 to 60% in other crops. One study suggested that root hairs account for up to 90% of the total uptake by plants when the soil P concentration is low (**Figure 1**).

Phosphorus Fertilization

A review of the behavior of P fertilizer described the major reactions as sorption, precipitation and organic interactions.

Sorption refers to the adsorption of soluble P to the surface of soil minerals. These reactions include fast and reversible reactions through a ligand exchange. They also include the slower penetration of P below the mineral surface. The sorp-

Abbreviations and notes: P = phosphorus; BMPs = Best Management Practices.



Figure 1. Relative root length and proportion of root hairs of three crop plants. From Thorton et al., 2014.

tion capacity of soil has a strong influence on the amount of fertilizer P required to meet the nutritional needs of potatoes. Soil tests account for much of the sorbed P that will become available for plant uptake during the growing season.

Precipitation occurs when added P fertilizer causes the soil solution to become over saturated with P and various solid minerals begin to form. The specific minerals that form and their persistence depends on many environmental and chemical factors. As time passes, the most soluble of these minerals may dissolve and less soluble minerals may recrystallize.

Organic P can contribute to potato nutrition. Much of the P added to soil in manures and composts is in the form of orthophosphate, initially behaving similarly to commercial P fertilizer. Soluble organic matter can inhibit P sorption in some soils and may also promote accumulation of organic P compounds, which can serve as a slow-release P source.

Placement of fertilizer P is critical for a potato plant to get the most benefit from its application, as the plant roots must grow into the soil zone influenced by the granule or droplet. Placing the fertilizer directly into the root zone increases the probability that a root will intercept the added nutrients. The failure of potato roots to intercept the fertilized micro-sites accounts for the relatively low first-year P recovery of 10% for broadcast fertilizer applications and 35% for banded applications. The unrecovered fertilizer P will contribute to the building of the general P concentration in the soil and can be used by succeeding crops.

Soil Testing

Soil testing is widely used to predict the need for additional fertilizer P to meet the demands of the potato crop. Although a variety of methods and extractants are used in different regions, they all determine if soluble P concentrations are below a critical level where additional P is required to achieve optimal yield. Soil testing should always be the first step in developing a P management program where it is available.

Plant tissue analysis is commonly performed to confirm P adequacy in the developing crop. Excellent resources exist to define the sufficiency of P concentrations during different stages of growth. When P deficiencies are found, in-season supplemental P applications are commonly made to alleviate any nutritional limitations.

The economically justified rates of P fertilization are much higher for potatoes than for many other crops. The positive yield response to P fertilizer often provides justification to applying P, even when the soil P concentrations are already high.

Phosphorus Stewardship

Since many potato production

fields often have relatively high soil P concentrations, they require special attention to prevent any off-field losses. Potato fields are at risk for loss of soluble P in surface runoff, particulate P with eroding soil, and P leaching in coarse-textured soils. Research has shown the need for special conservation efforts on fields of 6% slope or more. Implementing appropriate conservation practices in high-risk areas can minimize loss of P.

A seven-point recommendation of best management practices was suggested:

- 1. Begin a P management plan for potatoes with soil testing to determine the existing P concentration and establish the need for additional fertilization.
- 2. Base fertilizer P applications on calibrated potato response data. Excessive P fertilizer applications should be avoided for economic and environmental reasons.
- 3. Plan to apply a dose of P fertilizer at planting (with a minimum spacing from seed piece). Some potatogrowing regions recommend only banded P fertilizer



P-deficient potato plants often appear stunted with dark blue/green leaf coloration.



Potato crop starting to flower, Tasmania.

application, while other regions also use broadcast/ incorporated P fertilization along with banded fertilizer.

- The source of P fertilizer does not generally influence 4. potato performance. Avoid placing ammonium-based P fertilizers too close to the seed piece at planting.
- Monitor petiole P concentrations for determining the 5. need for in-season fertilizer applications. In-season foliar P applications will not satisfy the nutritional requirement of a severely deficient crop. Check the chemical compatibility of fertilizer and irrigation water prior to fertigation.
- Account for all P sources added to the field, including 6. animal manures and composts.
- 7. Adopt appropriate conservation practices to minimize the loss of P to water, especially on vulnerable fields with a high risk of loss and with very high P concentrations. **EC**

Acknowledgement

The symposium papers listed below are published in Amer. J. of Potato Research (2014) Volume 91, Issue 2.

- Fixen, P.E. et al. Potato Management Challenges Created by Phosphorus Chemistry and Plant Roots. pp.121-131.
- Hopkins, B.G. et al. Improving Phosphorus Use Efficiency Through Potato Rhizosphere Modification and Extension. pp.161-174.

Rosen, C.J. et al. Optimizing Phosphorus Fertilizer Management in Potato Production. pp.145-160.

- Ruark, M.D. et al. Environmental Concerns of Phosphorus Management in Potato Production. pp.132-144.
- Thornton, M.K. et al. Improving Potato Phosphorus Use Efficiency in the Future. pp.175-179.

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Faba Bean Fertilization in Morocco

By K. Daoui, M. Karrou, R. Mrabet, Z. Fatemi, and K. Oufdou

Faba bean represents one of the important annual food crops grown in Morocco. **Research is showing** that fertilizer, mainly P, management can contribute significantly to the increase of faba bean yields.

Food legumes (beans, chick peas and lentils) are very important for the nutrition of humans and animals, as well as for sustainable farming in Morocco and throughout North Africa.

Faba bean (*Vicia faba* L.) has many important advantages, both during its planting year and for crops that follow in rotation. These advantages include a large biological N fixation potential, and its positive impact of improving soil structure and health. Interest in legume crops is increasing as a means to ensure food and feed security, and as a benefit to soil ecology. However, productivity of food legumes in Morocco has remained low and variable. One possible reason for this is the absence, or the limited use, of mineral fertilizers. According to national statistics, about 50% of farmers use mineral fertilizer in food legumes, despite its well documented contribution to improving yield.

Nitrogen

The N requirement of faba bean is high, with about 80% of its need commonly from biological fixation (Zapata et al., 1987). Although the crop can fix N, it is often suggested to apply small amounts of fertilizer N at planting. The application of 20 kg N/ha at planting time has been shown to be beneficial for faba bean to enhance biological fixation (R'kiek, 1994). Daoui et al. (2010) indicated that this N application could be avoided because of the indeterminate growth habit of the crop, and limited rainfall. Their research showed that the application of 30 kg N/ha in different agro-ecological conditions, and with different varieties, had no significant effect on grain yield but instead reduced nodulation (**Figures 1** and **2**).

Phosphorus

In their study on the impact of P application on faba bean



Figure 1. Effect of starter N application on yield of four faba bean varieties (N0 and N+ = 0 N and 30 kg N/ha, respectively). Daoui et al. (2010). Error bars = Standard Deviation.

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



Figure 2. Effect of starter N application on nodule dry biomass for four faba bean varieties. (N0 and N+=0 N and 30 kg N/ha, respectively). Daoui et al. (2010) Error bars = Standard Deviation.

productivity Daoui et al. (2009) observed a positive effect of P fertilization on crop growth (i.e., leaf area, flowering, root growth, etc.) and grain yield. Maghraoui et al. (2014) showed that the inoculation of faba bean plants with phosphate-solubilizing rhizobia increased the plant dry weight and P uptake.

The response of faba bean to P application, in relation to initial soil P content, has been compiled from different studies conducted on different soils, years and climatic conditions (**Figure 3**). Results show that under Moroccan conditions, the critical level for pre-plant soil P (Olsen test) is 15 mg/kg. Negative effects of P application on yield when soil P content is higher than 15 mg/kg could be attributed either to antagonism with Zn (**Figure 4**) or to vegetative growth competing with reproductive growth, confounded by the indeterminate



Figure 3. Relationship between soil P concentration and faba bean grain yield response (Adapted from Amnay, 2010; Daoui et al., 2012)



Figure 4. Effect of P application on P and Zn concentrations measured in total biomass and foliar tissue of faba bean (Daoui, 2002). Error bars = Standard Deviation.

growth habit of faba bean.

Since P is less mobile in soil, its uptake is affected by whether it is broadcast or banded. According to Hoeft et al. (2000), plants often use 15 to 20% of broadcast P in the year of application, but 40 to 50% of P placed in a band near the early root growth zone. In Morocco, Amnay (2010) showed that the application of 120 kg P₂O₂/ha to soil with an initial Olsen P of 4 mg/kg could increase faba bean grain yield by 73% to 246%. However, banded application of P out-yielded broadcast P by 13 to 25%.

Phosphorus use efficiency (PUE) is variable among faba bean varieties (Daoui et al., 2012). Studies conducted during two years under two different soil P concentrations (11 mg/ kg and 5 mg/kg) showed significant genetic variation of PUE. Varieties with small seeds and high harvest index (producing less straw versus grain) had higher PUEs values at the higher soil P site. However, a larger seed variety appeared to have higher PUE at the low soil P site (data not shown).

Potassium

Under Moroccan conditions where K is deficient, K recommendations for faba bean production is about 90 kg K_aO/ha. However, according to soil analysis from the locations where faba bean is cultivated, scientists have not found research sites where there was a need for K application.

Summary

Although faba bean can fix N, studies conducted have focused on starter N application. Some results showed that



Faba bean nodulation with N application (left) and without N (right).

rate, mode of application (banded or broadcast) and on PUE based on genetic diversity. There is generally a beneficial effect of P application on grain production and nodulation. In addition, inoculation of faba bean with rhizobium strains showed a beneficial effect on the plant growth as well as phosphate uptake. For K, fewer studies have been conducted and all have shown no significant benefit on production since the soil where studies were conducted had high K concentrations. Dr. Daoui is Scientist in the National Institute of Agricultural Research

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Indeterminate faba bean plants: only the first flowering stages produce pods. the application of 20 kg N/ha is beneficial. However, other

results showed that the application of 30 kg N/ha at planting

in different agro-ecological zones and for different varieties of

faba beans had no significant effects on yield but negatively

affected nodulation. Regarding P, research has focused on the

Better Crops/Vol. 99 (2015, No. 4)

Warm-Season Grass Responses to Potassium and Phosphorus Fertilization

By Maria L. Silveira

Pasture fertilization plays a vital role in successful forage-based livestock production systems, but producers often under fertilize, and fail to replace nutrients removed at harvest.
 Long-term persistence of grass pastures and hayfields Is often related to adequate soil P and K.
 Large K removal in crops harvested from sandy-textured, low K-buffering soils can lead to severe K deficiency.

In the southeastern U.S., forage-based livestock systems rely on warm-season perennial grasses such as bermudagrass (Cynondon dactylon), bahiagrass (Paspalum notatum), and limpograss (Hemarthria altissima). More specifically in Florida, bahiagrass is the predominant cultivated grass occupying approximately 2 million acres in the state. While bahiagrass is widely used in low input systems with limited (or no) fertilizer inputs, other grasses such as hybrid bermudagrass and limpograss are important forage crops for both dairy and beef cattle producers because of their greater yield potential and better nutritive value. However, because of the greater yields, these grass species require relatively higher fertilization compared to other less productive grasses like bahiagrass.

If a soil tests low or medium for P, fertilizer recommendations for bermudagrass (Jiggs variety) and limpograss grown for hay in Florida consist of 80 lb N/A, 20 lb P_2O_5/A and 40 lb K_2O/A after each cutting For grazing, the recommended application rates are 160 lb N/A, up to 40 lb P_2O_5/A and 80 lb K_2O/A depending on soil test results. The need for routine use of micronutrients has not yet been demonstrated.

Despite the University of Florida recommendations for K and P fertilization, many forage producers do not supply adequate K and P to replace the nutrients removed as harvested forage. Consequently, soil K concentrations (and to a lesser extent soil P) decline, which often results in poor stand persistence and greater incidence of diseases and insect damage.

The objective of this 3-yr field trial was to evaluate Jiggs bermudagrass and limpograss responses to K and P fertilization. The study was conducted on established bermudagrass and limpograss fields at the University of Florida, Range Cattle Research and Education Center, Ona, FL on a Ona fine sand. Treatments consisted of minimum fertilization regimens that could maintain optimum forage yield, nutritive value, and stand persistence. Potassium and P were applied in April of 2012, 2013 and 2014 at annual rates of 0, 40 and 80 lb K 0/A and 0, 20 and 40 lb P₂O₅/A, respectively. Nitrogen was applied at an annual rate of 80 lb N/A. Nitrogen was applied as ammonium nitrate and P and K as triple superphosphate and potassium chloride, respectively. Plot size was 20 x 10 ft. for bermudagrass and 13 x 10 ft. for limpograss. Initial soil pH was 5.3 and Mehlich-1 extractable P, K and Mg concentrations were 23, 12 and 293 lb/A, respectively. These concetrations are medium for P, very low for K, and very high for Mg. For-

Abbrevations and notes: N = nitrogen; P = phosphorus; K = potassium; Mg = magnesium. IPNI Project USA-FL31.



Jiggs bermudagrass grown in plots (3rd year of experiment) receiving 0, 40 and 80 lb K_2O/A at Ona, Fl.



 ${\rm Limpograss}$ grown in plots (3rd year of experiment) receiving 0, 40 and 80 lb K,O/A, at Ona, Fl.

age was harvested at 6-week intervals for four harvest events per year to determine dry matter yield and nutritive value. Dry matter yield was determined by harvesting two 3- x 10-ft forage strips from each plot to a 3 in. stubble height using a forage harvester. The remaining herbage was harvested to the same stubble height using a sickle bar mower and removed from the plots.

Temperature patterns observed during the 3-yr study were typical for the region, with exception of 2013, which experienced significant freezing temperatures in March. Rainfall during the study period was 20% below average in 2012 and 2013. The drought conditions experienced in the beginning of the 2013 growing season contributed to decreased forage production during that year.

Bermudagrass Responses

Bermudagrass dry matter yield increased linearly as annual K fertilization rates increased (Table 1). No yield response to P fertilization was observed. Cumulative annual dry matter yield for the treatments receiving K increased by 26 to 377% relative to the control treatments (no K added). The largest differences between control and K-receiving treatments were observed in 2014. During this year, K fertilization increased bermudagrass dry matter yield by as much as 377% (5,357 lb/A for the treatment receiving 80 lb K₂O/A compared to 1,124 lb/A for the controls). Bermudagrass dry matter yield in 2013 was considerably lower than those reported in 2012 and 2014 due to unfavorable climatic conditions experienced during that year. Average crude protein concentrations across the 3-yr study were greater in the controls compared to the treatments receiving K (Table 1). This occurred because of a dilution effect as a result of greater dry matter yield observed in the treatments receiving K.

Regardless of the K fertilization rates, bermudagrass dry matter yield generally decreased over time during the study period. These data indicated that K fertilizer rates applied during the 3-yr study were not sufficient to sustain the production. In addition, considerable stand losses and concomitant weed infestation occurred at the end of the 3-yr study, particularly in the treatments receiving no K (**Table 1**). Bermudagrass frequency (i.e., species occurance within a given area) and ground cover both ranged from 50 to 54% in the treatments receiving K compared to 31 to 37% in the control treatments.

Limpograss Responses

Limpograss dry matter yields increased linearly as K fertilization increased (Table 2). Relative to the control treatments (no K added), K fertilization increased annual dry matter yield by 17 to 24% when K was added at an annual rate of 40 lb K_0O/A and from 38 to 47% when 80 lb K_0O/A was applied. In the absence of K fertilization, dry matter yield decreased significantly during the 3-yr study. However, during the same period, no significant decline in dry matter yield was observed for the treatments receiving K, indicating that limpograss can maintain adequate production with relatively low rates of K fertilization. Treatments receiving K sustained adequate ground cover over the study period (average of 88% ground cover); however, there was a significant stand loss (65% ground cover) in the treatments that did not receive K. This response suggested that despite the apparent lower requirement, adequate K fertilization is important to maintain limpograss persistence. Limpograss crude protein concentrations also decreased as K fertilization rates increased (Table 2).

Summary

Potassium fertilization resulted in greater bermudagrass and limpograss dry matter yield and decreased stand loss in the 3-yr study. Despite the positive effect of K, bermudagrass dry matter yield observed in year 3 was significantly lower than those obtained in the first year of study. Considerable stand losses and concomitant weed infestation occurred by

Table 1.	Jiggs bermudagrass	dry matter yie	ld, frequency,	ground	cover, and	crude protein c	on-
	centration as affecte	d by K applica	tion rate.				

	Dr	y matter yiel	d			
Annual K ₂ O application	2012	2013	2014	Frequency ¹	Ground cover ¹	Crude Protein ²
	- lb/A/yr				%	
0	4,536	820	1,124	37	31	15.2
40	5,719	1,815	3,959	50	52	14.0
80	6,517	2,216	5,357	54	54	13.7
Standard error	343	129	267	1	1	0.2
Orthogonal Contrast	Linear***	Linear**	Linear***	Linear***	Linear***	Linear***

¹Frequency and ground cover were measured at the end of 2014 growing season.

²Values represent the 3-yr average.

 $^{**}p \le 0.01; ^{***}p \le 0.0001$

 Table 2. Limpograss dry matter yield, frequency, ground cover, and crude protein concentration as affected by K application rate.

	Dr	y matter yiel	d			
Annual K ₂ O application	2012	2013	2014	Frequency ¹	Ground cover ¹	Crude Protein ²
	- lb/A/yr				%	
0	12,408	4,189	8,779	60	65	6.7
40	11,015	4,921	10,947	92	87	6.2
80	12,135	5,798	12,900	94	89	6.1
Standard error	1,200	360	900	1.2	1.4	0.1
Orthogonal Contrast	NS	Linear***	Linear***	Linear**	Linear***	Linear*

¹Frequency and ground cover were measured at the end of 2014 growing season.

²Values represent the 3-yr average.

NS= not significant; $*p \le 0.05; **p \le 0.01; ***p \le 0.0001$

the end of the study. Although the amounts of K exported via above-ground biomass were, in general, similar or less than those applied as fertilizer, K fertilization at application rates tested in this study were likely not sufficient to sustain production during the 3-yr study. Data also indicated that limpograss might require relatively lower application rates of K fertilization than bermudagrass to sustain production and stand persistence. No effects of P on bermudagrass and limpograss responses were observed. Results from this study suggested that continuous aboveground removal without proper K fertilization will result in decreased forage performance, stand loss, and increased weed infestation. Adequate K supply is essential to sustain bermudagrass and limpograss productivity and long-term persistence. **R**

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4R Nutrient Management for Banana in China

By Lixian Yao, Guoliang Li and Shihua Tu

A review organized within the 4R Nutrient Stewardship framework demonstrates yield and guality boosting practices for banana grown within southern China.

anana is widely grown in southern China. The crop covers 400,000 ha, which produces 12 million t. Banana's unusually high biomass yield requires a much larger quantity of nutrients than other common field crops. However, in practice, both over- and under-applications of fertilizers coexist. In fact, surveys reveal that differences between the high and low fertilizer rates used for banana in a given location can be up to ten times (Yao et al., 2006). Inappropriate fertilizer applications to banana can significantly reduce yield, quality, economic returns, and potentially pose a threat to the environment. The 4R Nutrient Stewardship approach to nutrient management considers the right fertilizer source in combination with the right application rate, timing, and placement. Considered together, the 4R management approach can improve profitability, nutrient use efficiency and promote sustainable fertilizer use.

Right Source

Banana responds to a wide range of fertilizers and those commonly applied include: urea, ammonium sulfate [(NH₄)₂SO₄], single superphosphate (SSP), monoammonium phosphate (MAP), diammonium phosphate (DAP), potassium chloride (KCl), potassium sulfate (K₂SO₄), calcium nitrate $[Ca(NO_3)_2]$, magnesium sulfate (MgSO₄), zinc sulfate (ZnSO₄), borax, and boric acid. Recent research has revealed that controlled release urea (CRU), as compared to regular urea, can reduce both rates and frequency of applications, and increase yield of banana as well as N use efficiency.

Each of the fertilizers mentioned above can be used separately, and most can be mixed in different proportions or formulated into specialty compound fertilizers for banana. Nevertheless, evidence suggests a preference for nitrate (NO₃⁻ -N) over ammonium $(NH_{4}^{+}-N)$ at the seedling stage, with the optimal NO_3^- : NH_4^+ ratio being 9:1 (Wang, 2012).

It has been common perception that K_2SO_4 is superior to KCl as a K source for banana, but research has demonstrated that partial replacement of KCl with K₂SO₄ often has little impact on growth, fruit yield and quality of banana (Table 1). Of course, this can be attributed to the soil containing sufficient S, and to abundant rainfall able to leach any excess Cl⁻ out of soil profile. In regions where soil S is inadequate or deficient,

it is necessary to include an appropriate S source.

Right Rate

The nutrient requirement of banana varies with crop variety, location (climate), and yield goal. To achieve a yield goal of 60 t/ha in the southern province of Guangdong, banana generally needs 4.6, 0.41, 15, 2.5, and 1.2 kg of N, P, K, Ca, and Mg, respectively, to produce 1 t fruit (Yao et al., 2005).

Table 1. Banana fruit characteristics, yield, quality and profit as affected by K sources (Yao et al., 2014-2015, unpublished data)

((
	Finger length,	Finger girth,	Hand weight,	Solid,	Vit. C,	Soluble sugar,	Fruit yield,	Profit,
Treatment	cm	cm	kg/hand	%	mg/100g	%	t/ha	US\$/ha
KCI	26.4	13.2	3.36	23	6.54	17.6	47.04 a	11,026
K ₂ SO ₄ +KCl (25:75)	27.3	13.3	3.00	23	6.73	17.7	47.10 a	11,007
N, P ₂ O ₅ and K ₂ O rates were 975, 245 and 1,072 kg/ha with retail prices (US\$) of 0.64/kg N, 0.66/kg P ₂ O ₅ and 0.45 (KCl) or 0.59 (K ₂ SO ₄)/kg K ₂ O, respectively. Banana price was US\$0.26/kg.								

Banana plantation in southern China.

Nitrogen and K are required in the largest amounts by banana. Accordingly, N and K usually become the most limiting nutrients for yield and quality. Soil test-based recommendations for fertilizer N and K rates for the fertile Pearl River Delta region and less fertile, western Guangdong are provided in

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Ca = calcium; Mg = magnesium; Cl⁻ = chloride.



Table 2.Rating of available soil N and K in relation to amounts of fertilizersrecommended in Pearl River Delta and western Guangdong.							
Region	Soil available N, mg/kg	N recommended, kg/ha	Soil available K, mg/kg	K recommended, kg K ₂ O/ha			
	>180	330-390	>300	450-525			
	150-180	390-450	200-299	525-600			
Pearl River	120-149	450-510	150-199	600-675			
Delta	90-119	510-570	100-149	675-750			
	60-89	570-630	50-99	750-825			
	<60	630-690	<50	825-900			
	>180	390-450	>300	600-675			
	150-180	450-510	200-299	675-750			
Western	120-149	510-570	150-199	750-825			
Guangdong	90-119	570-630	100-149	825-900			
	60-89	630-690	50-99	900-975			
	<60	690-750	<50	975-1,050			

Table 3.Percentage of N, P and K fertilizer allocations at differ- ent growth stages of banana in Guangdong (Yao et al., 2004).							
Growth stage	Ν	P_2O_5	K ₂ O	Mg			
		%					
Vegetative	25	100	20	0			
Flower development	45	0	50	50			
After bud shooting	30	0	30	50			

Table 2. The amount of P required by banana can usually be calculated based on the N rate, multiplying N rate by a factor of 0.28 to 0.3 for the Pearl River Delta and 0.24 to 0.28 for western Guangdong based on soil P status (Yao et al., 2005).

Fertilizer application rates generally increase along with the higher rainfall and temperatures experienced in the more southern production zones. The best K₂O:N application ratio for the Pearl River Delta region ranged between 1.12 to 1.2:1, but in western Guangdong it tends to be wider at 1.25:1. In neighboring Fujian Province, K₂O:N ratios of 1.67 and 1.39 have been reported for high and low yield banana orchards, respectively (Zhang et al., 2015).

Fertilizer K, when used at high rates, can inhibit uptake of Mg due to the competitive relationship observed between the two nutrients. Care should be taken in areas where soil Mg is inadequate or deficient. Since soil Mg deficiency is a widespread problem in most banana orchards in China, the amounts of Mg fertilizer used to correct Mg deficiency, in addition to meeting the K x Mg interaction, must appropriately balance with the amounts of K being added. For example, in western Guangdong application of 36 kg Mg/ha is adequate to correct Mg deficiency when the K rate is 990 kg K₂O/ha, while 72 kg Mg/ha is needed when K rate rises to 1,170 kg K₂O/ha. It is crucial to maintain an adequate Mg supply to promote yield and prolong the critically important shelf-life characteristic of banana.

Right Time

The quantity of nutrients required by banana varies with growth stages and this is well reflected in the nutrient concentration in leaves (**Figure 1**). Nitrogen concentrations in leaves remain stable during the vegetative stage, but decline from floral bud differentiation to bunch harvest. Potassium concentrations keep increasing from vegetative stage until the bud shooting stage and then gradually decline with further plant growth. Flower bud development stage (the period between bud differentiation to bud shooting) is very crucial for plant N and K nutrition. During this period the dominant nutrient metabolism evolves from N to both N and K. Thus, sufficient K should be supplied before bud shooting as well as at the fruit finger swelling stage. Farmers commonly apply the majority of K after the bud shooting stage, which misses one optimal timing opportunity, and leads to low K use efficiency.

Leaf Ca and Mg concentrations show an opposite pattern to K concentration (**Figure 1**), once again demonstrating their competitive re-

lationship and emphasizing an importance for seasonal supply of the two nutrients. Application of SSP and lime on the acidic soils of southern China can supply sufficient Ca to banana, but the addition of Mg fertilizer also becomes a necessity. If available, dolomitic lime is a better alternative to calcium carbonate under conditions of both Ca and Mg deficiency.

Leaf P and S concentrations remain low and constant through the growing season, indicating a relatively low requirement and an appropriate maintenance nutrient supply.

Nutrient accumulation in the banana plant also varies considerably with growth stage. Accumulation of N, P and K in the plant accounted for 19.3%, 17.8% and 16.5% at vegetative stage, 40.5%, 45% and 52.6% at floral bud development stage, and 40.2%, 37.2% and 30.9% after bud shooting stage (**Figure 2**).

Based on characteristics of nutrient uptake and accumulation, and years of experience, Yao et al (2004) suggested the percentages of N, P and K fertilizer allocations at different banana-growing stages in Guangdong (**Table 3**).

Frequent and small doses, rather than fewer, large appli-



Figure 1. Nutrient concentrations in banana leaves at different growth stages (Yao et al., 2005).

cations of N fertilizer are preferred, unless controlled-release fertilizers can be used. Usually, N fertilizers are split six to eight times within one growing season. This includes one basal application, one or two side-dressings at the vegetative stage, two splits at the flower development stage, and one or two at the fruit-swelling stage. Using CRU instead of regular urea can reduce N applications to one basal application and one side-dressing (at flower development stage) to achieve the same or even higher yield goals. Phosphate fertilizer is usually only applied in one basal application, unless drip fertigation is used. Most of the N and K fertilizers are applied at the flower development stage and fruit-swelling stage because such allocations can significantly enhance fertilizer use efficiency (Murthy and Iyengar, 1995).

Right Place

Banana has a typical fibrous root system that is mainly distributed within the top 10 to 50 cm of soil. The most rapid root development occurs at the flower differentiation stage in banana. During this stage roots can grow up to 235 cm in length, but 45 cm is the average (Table 4). As buds emerge, the

Table 4.Characteristics of banana roots at different growth stages (Pearl River Delta; Yao, 2008, unpublished data)						
Growth stage	Maximum root length, cm	Average root length, cm	Root number per plant			
Vegetative	-	-	76			
Flower bud differentiation	236	46	230			
Bud shooting	108	35	239			
Fruit swelling	193	36	321			

mean root length starts to decline, but roots keep proliferating to sustain its overall nutrient demand. Based on these rooting patterns, fertilizers should be banded or hole applied into the rooting zone or around the drip line about 35 to 50 cm from the pseudostem base.

Though drip fertigation has become a more popular practice in China, most farmers use traditional methods of broadcasting, banding. Li et al. (2011) compared different methods of fertilizer application and found no differences in yield and quality (Table 5). Despite the highest yield produced from a fertigation + banding treatment (i.e., fertigation before shooting and banding thereafter), broadcasting throughout the season achieved the highest profit due to a lower labor cost. During the fast-growing, mid-to-late growing stage period that usually coincides with the hot and rainy season, surface broadcasting followed by covering with soil can be a better alternative to avoid root damage-induced infection from Fusarium wilt due



Figure 2. Percentage of N, P and K accumulation in banana plant at different growth stages.

to soil disturbance within the root zone, and at the same time to enhance fertilizer use efficiency.

Summary

Implementation of improved nutrient management can not only improve banana yield, but also narrow the current yield gaps and enhance nutrient use efficiency and environment protection. The actual nutrient needs of banana largely depend on local variety, soil fertility, yield goal, and weather conditions. Appropriate fertilizer timing and placement must coincide with banana growth stages for maximum nutrient uptake and better yield and quality. The 4R Nutrient Stewardship approach provides a framework to identify the best options to meet banana's nutrient demands.

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Table 5.	Banana yield,	quality and econor	nic returns as affecte	d by methods of	fertilizer application	s (Li et al., 2011)
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	Yield, t/ha	Soluble solids	Soluble sugar	Vit. C	Output	Cost	Profit
Treatment		%	6	mg/100g		US\$/ha	
Broadcasting	49.85 a	21.7 a	16.74 a	9.08 a	16,343	7,928	8,415
Broadcasting + banding	48.75 a	22.7 a	17.28 a	9.52 a	15,984	8,616	7,367
Fertigation + broadcasting	48.87 a	22.5 a	17.20 a	8.75 a	16,025	8,223	7,802
Fertigation + banding	50.72 a	22.0 a	18.12 a	9.30 a	16,628	8,961	7,667
Different letters following means within columns indicate a significant difference at $p < 0.05$.							

AUSTRALIA

Phosphorus Requirements for Cereals: What Role Does Crop Rotation Play?

By Andreas Neuhaus, James Easton and Charlie Walker

A network of field data refines critical soil test values for cereals based on the interaction between previous crop and soil P immobilization.



Strong response to P (29 kg P/ha) in wheat grown after canola on high phosphorus buffer index (>120) soil with Colwell P of 60 to 80 mg/kg. Control (zero P) is shown on the right in each photo.

Phosphorus recommendations in Australia are based on the Colwell P soil test. When used alone, this test sometimes shows poor correlation to yield responses (Mason et al., 2010). Using such weak correlations is likely to lower farm profits and reduce confidence in soil testing.

Cereal crops dominate the broad-acre systems in Australia. However, the common insertion of other rotational "break" crops adds an additional factor to consider when trying to determine the P requirement for any cereal that follows a break crop. Lush (2014) highlighted examples of different P requirements for wheat following cereals compared with wheat following either canola or legumes.

This study investigated P requirements in different cereal rotations using data from more than 100 field trials. The data used was from field research undertaken by two major fertilizer companies in Australia [CSBP Ltd. and Incitec Pivot Fertilisers (IPF)], as well as from the "Making Better Fertiliser Decisions for Cropping System in Australia" (BFDC) project (https:// www.bfdc.com.au).

The BFDC project developed an interface that allows users to filter P-responsive field trials by various factors to improve soil P x yield response correlations. Insufficient data exists to filter by phosphorus buffer index (PBI – an index of a soil's

Abbreviations and notes: P = phosphorus; OC = organic carbon.

ability to "lock-up" or adsorb P) or gravel content, which are factors suggested by Bell et al. (2013) as likely to improve the soil P x yield response relationship. Crop rotation is another factor interacting with the pools of plant available and sorbed soil P.

This study was undertaken because it has potential use for a) improving P soil tests; b) correlating/modelling the Colwell P x yield response curve in combination with other factors like soil type, pH or crop sequence; and c) investigating the dynamics of P cycling in different crop rotations. Applying a better understanding of interactions between PBI, Colwell P and crop rotation may improve P management on farms and also benchmark studies on soil P status.

The dataset contained 53 CSBP cereal field trials conducted in Western Australia (WA) from 2000 to 2014 with maximum yields from 1.5 to 6.5 t/ha. Trials, mainly wheat and barley, were on gravelly and non-gravelly soils, ranging from sand to clay. BFDC provided 43 trials [18 from South Australia (SA), 17 from WA and 8 from New South Wales (NSW)]. IPF made 6 trials available from Victoria (Vic)/NSW.

Results

Field trials showed a trend towards higher critical Colwell P for cereals on canola, especially on higher P sorption soils (**Figure 1**). Cereal after canola formed a different cluster to the other rotations on soils with a $PBI_{+ColP} > 70$ (classified by

20



Figure 1. Relative yield in response to Colwell P. High phosphorus buffer index (PBI) plus Colwell P (PBI_{+ColP}) values are shown next to symbols (○) denoting cereal trials after canola. Darker and lighter filled symbols show cereal trials on soils above and below PBI_{+ColP} 70, respectively. The bottom and middle fitted calibration curves belong to cereal trials after canola (dotted line for PBI_{+ColP} > 70; dashed line for PBI_{+ColP} < 70) while the top curve is for all other trial data (solid line). Symbols represent the previous crop as cereals (□), pasture (◊) and lupins (Δ).</p>

the Australian P sorption status as being above "very low") and improved soil test x relative yield relationships when fitted separately (**Figure 1**). Regression correlation coefficients (r) for previous crops in **Figure 1** were: 0.03 (canola; $PBI_{+CoIP} < 70$), 0.50 (canola; $PBI_{+CoIP} > 70$), 0.16 (cereals), 0.58 (pasture) and 0.76 (lupins). Consideration of subsoil Colwell P (10 to 20 cm) did not improve soil P x yield correlations.

Correlations between Colwell P and yield were weak, highlighting risks with decision making based on this factor alone. Using a principal component analysis, P yield response was affected by factors that were at least as important as Colwell P. Those factors, shown here in scatter plots, were soil OC% and PBI (PBI_{+ColP}), while for example pH_{CaCl2} was of lower importance (**Figure 2a-c**).

Colwell P has traditionally been regarded as the most important variable for P responses. This study found that measures of the capacity of the soil to immobilize P such as OC and PBI_{+ColP} are of at least equal importance when generating P recommendations, in particular for a canola-cereal rotation. Canola extracts more P from the soil, but also leaves more residual P in its residue than cereals due to its higher biomass production (or lower harvest index). Inorganic and organic forms of P in canola could account for a large percentage of the initial P supply during cereal plant establishment. This P may become available to the next crop depending on the mineralization and soil P sorption capacity. Doolette et al., (2012), however, observed higher P mobilization and availability after lupins, but not after canola. Both crops are non-hosts for arbuscular mycorrhizal fungi (AMF). Despite the lack of AMF, a higher P uptake in wheat following canola or legumes has been reported (Lush, 2014) and hypothesized to be a result of a healthier cereal root system and increased root length as a result of improved N availability after rotational break crops.

This study cautions against relying on higher P availability after break crops. Based on trial data presented here, it is speculated that after canola a higher proportion of the mineralized P is less plant available on higher PBI_{+ColP} soils. While the P cycle under contrasting PBI's is not investigated here, the data clearly suggest applying above maintenance P rates after canola on higher PBI soils to reduce the risk of under-fertilizing if no soil samples are taken for Colwell P.

Querying of the national BFDC database gave a critical Colwell P (95% max yield) of 34 mg/kg with a range of 29 to 40 (r = 0.47) for wheat trials where a cereal was the previ-

ous crop. Wheat following canola had a higher critical Colwell P of 49 (range 17 to 140) while wheat following a pulse crop had a lower critical Colwell P of 30 (range 17 to 53). These last two data sets were smaller, with weaker correlations of 0.24 and 0.35, respectively.

The critical Colwell P values obtained in this study only partly match outcomes of the BFDC project. Those previously reported critical Colwell P values by the BFDC project seem to hold only for "very low" PBI_{+ColP} soils (< 70). The critical Colwell P for 95% maximum cereal yield on PBI_{+ColP} soils > 70 was about 110 mg/kg. Cereals following lupins fitted the same yield curve as cereals following pasture or cereals. Interestingly a higher PBI_{+ColP} did not necessarily result in a higher critical Colwell P, but instead depended on crop rotation.

Crop rotation affects soil test interpretation for fertilizer P recommendations. Multifactorial crop modelling is best suited to improve P recommendations, especially for areas with gravelly forest soils in WA (**Figure 3**) and in the south eastern states (NSW, Vic, SA, Tasmania) where 40 and 8% of cropping soil tests fall into the category represented by orange and red, respectively.

Phosphorus deficiencies have been reported after canola even when fertilized according to critical soil test levels (Bowden et al., 1999). Different P distributions, positional availability problems, lack of AMF and root pruning after canola have been suggested as contributing factors to reduced P availability under higher PBI scenarios. Even more factors could affect P availability [i.e., P placement, P source and cereal cultivars that differ in P-use efficiency (Bell et al., 2013)]. Further confounding factors can be early periods of



Figure 2. Relative yield in response to (a) PBI + Cowell P, (b) organic carbon, and (c) pH_{CaCl2} . Darker and lighter filled symbols show cereal trials on soils above and below PBI_{+ColP} 70, respectively. Linear trend lines with equations are only for cereal trials after canola (\circ) on soils with PBI_{LColP} > 70. Other symbols represent the previous crop as cereals (\Box) , pasture (\Diamond) and lupins (Δ).



Figure 3. The phosphorus buffer index (PBI) map of Western Australia, grouped according to the national PBI categories, highlights locations of soils with PBI's above 70. These are marked in orange (10% of total samples) and red colors (5% of total samples) and can be described as mainly gravelly forest soils.

dry growing conditions, water repellent soil or a compacted soil layer in the profile. Despite all the complexities, this study refines critical Colwell P values, improves decision support systems for P recommendations, and could improve survey or benchmark reports for soil P status.

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Residual Potassium Effects on Corn under No-Tillage

By Frank Yin and Guisu Zhou

The residual effects of long-term surface broadcasting of K fertilizer to preceding cotton provided sufficient K to three successive no-till corn crops.

roduction acreage of a specific crop or crop rotation at least partially depends on the crop prices. It has become more common to grow the same crop continuously for several years or even longer on the same fields for optimum profit then switch to another crop due to changes in crop prices. Opportunities to study the nutrient management implications of a cropping change tend to be uncommon. Here, the residual effects of K, surface applied in no-till cotton for 14 years, is examined in successive no-till corn crops planted after cotton.

A cotton trial was conducted at Jackson, TN during 1995 through 2008 to evaluate the effects of K application rates on cotton K nutrition and yield under no-tillage. The soil was a Loring silt loam. The initial Mehlich 1 soil K concentration in 0 to 15 cm depth was 100 mg/kg, which is equivalent to 139 mg/kg under Mehlich 3 extraction in Tennessee. Potassium was applied annually at rates of 0, 28, 56, 84, 112, 140, and 168 kg K/ha in a randomized complete block design with three replicates. The K treatments were broadcast by hand to the soil surface as KCl before cotton planting in each season.

A corn trial was conducted on the same field from 2009 to 2011 with the same experimental design and plot layout used for the previous cotton seasons. No K fertilizer was applied to corn during any of the three years. Corn was no-till planted in 76-cm rows in the same direction as the previous cotton crops. Corn cultivar DKC69-40 was planted at 69,000 to 74,000 seeds/ha. Each year, 3 to 4 weeks after corn planting, UAN was injected 6 to 8 cm deep and 20 cm away from each corn row at a rate of 168 kg N/ha.

Soil Nutrient Concentrations

In the fall of 2008, prior to the initiation of the corn trial, soil K concentrations differed among the historical K application rates (Table 1). It was obvious that soil K increased markedly as the K application rate increased. According to the boundaries of soil-test K in low, medium, high, and very high categories of <60, 60 to 96, 97 to 180, and >180 mg K/ kg, respectively, under Mehlich 3 for corn in Tennessee (Savoy and Joines, 2009), soil K fertility in the fall of 2008 was in the medium range under zero K, but high with the applications of 28 and 56 kg K/ha, and very high with 84, 112, 140, and 168 kg K/ha.

Compared with the initial soil K concentration of 139 mg K/kg before the initiation of the previous cotton trial in 1995, soil K had decreased under 0 and 28 kg K/ha, but had increased with the 56 kg/ha and above K rates during the 14 seasons of continuous cotton production under no-tillage. Since application of 56 kg K/ha annually was the recommended rate for cotton when a soil tested high in K (Savoy and Joines, 2009), our results showed that after 14 years of K application

Abbreviations and notes: K = potassium; UAN = urea ammonium nitrate; KCl = potassium chloride.

subsequent corn production.									
	Mehlich 3-extractable soil K concentrations (fall)								
	2008+	2009	2010	2011					
K applied, kg/ha		m	g/kg						
0	62g‡	83f	69f	87e					
28	98f	103ef	82ef	97d					
56	162e	148de	111de	146cd					
84	221d	171cd	129cd	187ab					
112	259c	205c	140bc	182bc					
140	312b	260b	192ab	206a					
168	371a	315a	231a	255a					
Sig§	***	***	***	***					

 Table 1. Residual effects of K applied to previous cotton crops

on Mehlich 3-extractable soil K concentrations during

*** Significant at p = 0.001.

+ In 2008, a Mehlich 1 extractant was used to determine soil K concentrations. The concentrations were then converted to Mehlich 3 values using the formula: Mehlich 3 K = $1.27 \times$ Mehlich 1 K + 12.0 (University of Kentucky, 2013).

[‡] Means in a column followed by the same letter are not significantly different at p = 0.05. § Sig, significance.

at the recommended rate via surface broadcasting, the soil K concentration was enhanced relative to the initial soil K fertility of 139 mg K/kg in 1995 although the K ratings for 2008 and 1995 both fell in the high category. In contrast, the soil K concentration decreased from 139 to 62 mg K/kg, and the K rating changed from the high category to the lower limit of the medium range, under the zero K treatment during the 14 years of no-till cotton production.

At the end of first year of the corn trial in the fall of 2009, soil K concentration differed among the K treatments (Table **1**). A similar trend was observed in the fall of 2010. By the end of corn trial in the fall of 2011, soil K concentrations were still different among the K treatments. Applying 28, 56, 84, 112, 140, and 168 kg K/ha resulted in higher soil K concentrations than zero K.

Leaf and Grain K Concentrations

Potassium applied to previous cotton exerted consistent residual effects on leaf K concentrations of subsequent corn at V6 and R1, regardless of year (Table 2). As the K application rate went up, the increase in leaf K gradually decreased. However, the residual K effects on grain K were negligible. Unlike soil K, the residual K effects on leaf K did not diminish remarkably with year, regardless of K treatment.

Campbell and Plank (2011) recommended that the range of adequate leaf K concentrations was 20 to 30 g/kg at V6 and 18 to 30 g/kg at R1 for corn grown in the southern U.S.

 Table 2. Residual effects of K application rates to previous cotton on leaf and grain K concentrations of subsequent corn from 2009 to 2011.

	20	09		2010				
	Ear leaf K R1+	Grain K	Leaf K V6	Ear leaf K R1	Grain K	Leaf K V6	Ear leaf K R1	Grain K
K applied, kg/ha					g/kg			
0	13.3f‡	3.4	11.9f†	13.2f	3.7	8.9f	13.8f	3.6
28	20.9e	3.3	20.7e	17.7e	3.7	19.7e	18.4e	3.4
56	24.0de	3.9	34.5d	22.9d	3.8	34.6d	24.3d	3.8
84	25.7cd	3.5	36.7bc	24.9bc	3.5	39.9a	26.4ab	2.6
112	26.1bc	3.5	39.6ab	24.9cd	3.5	38.5bc	26.3bc	4.2
140	27.8a	3.6	39.6ab	27.1a	3.9	37.6cd	25.9cd	3.8
168	27.7ab	3.5	36.7cd	25.7ab	3.6	39.3ab	27.3a	4.2
Sig§	***	ns¶	***	***	ns	***	***	ns

*** Significant at p = 0.001.

+ V6, 6-leaf growth stage; R1, silking stage.

 \ddagger Means in a column followed by the same letter are not significantly different at p = 0.05

§ Sig, significance.

¶ ns, not significant at p = 0.05.



Figure 1. Relationship of grain yields of corn with K application rates to previous cotton from 2009 to 2011.

According to these criteria, leaf K concentrations at V6 and R1 from the zero K treatment were consistently far below the sufficiency ranges, regardless of year, implying that corn plants did not have adequate K nutrition for optimum yield without additional K fertilization in the zero K treatment in this trial. However, leaf K concentrations at both V6 and R1 in all Kapplied treatments were equal to or markedly above the lower limit of the sufficiency ranges, depending on the K application rates. Leaf K concentrations at V6 were even greater than the upper limit of the sufficiency range at the 56, 80, 112, 140, and 168 kg/ha K rates due to luxurious uptake. Therefore, corn yield responses to K applications to the previous cotton crop were expected in all three years, based on the obviously deficient leaf K concentrations from the zero K treatment and significant increases in leaf K with K applications, if the recommended adequate leaf K ranges were indicative of final corn yield. Our results suggest that application of K fertilizer at the recommended rate of 56 kg/ha or above to the previous cotton crop via surface broadcasting for 14 continuous years could provide a sufficient amount of K to subsequent no-till corn for at least three years.

Grain Yield

The residual effects of K application rates to previous cotton were not significant on grain yield of subsequent corn in any of the three years (data not shown). Although leaf K concentrations at V6 and R1 were consistently and significantly improved under the K-applied treatments, grain yield at harvest did not benefit from those improvements. However, a significant quadratic relationship was observed between corn yields and K application rates to previous cotton in 2010 and 2011 (**Figure 1**). Generally, corn yield increased as the K rate went up to 94 kg/ha in 2010 and 84 kg/ha in 2011, and then decreased as the K rate increased further.

Potassium Removal by Grain due to Harvest

An accurate accounting of K removal from the soil by corn grain due to harvest is important in corn K management planning. Potassium removal by grain ranged from 2.54 to 3.55 kg K/t of grain at 15.5% moisture with an average of 3.10 kg K/t of grain in our study (**Figure 2**). Our results also showed that the K removal by grain varied with the growing seasons.

Our results are lower than the published grain K removal estimates. For instance, a K removal of 3.96 kg K/t of corn grain was reported in Alabama (Mitchell, 1999). Mallarino et al. (2011) estimated the K removal to be 4.46 kg K/t of corn grain in Iowa. Avila-Segura et al. (2011) found that the K removal was 3.6 kg K/t of corn grain averaged over a 6-yr study in Wisconsin. In the Eastern U.S., Heckman et al. (2001) reported that K removal by corn grain was in the range of 2.67 to 5.19 kg K/t of corn grain with an average of 4.00 kg K/t of corn grain across 23 locations in five states. Preceding measurements of K removal indicate that K concentration in harvested corn grain vary considerably across locations and



Figure 2. Distribution of corn grain K concentrations within Box and Whisker plots from 2009 to 2011 and the three-year combined data. The median K concentration is shown within the box (interquartile range) while the whiskers represent the upper and lower quartiles of the data.

growing conditions, with some tendency to increase with soil K concentration and corn yield (Heckman et al., 2001).

So far, little is known about the variation in grain K concentration with grain yield of corn. The regression analysis showed that grain K concentration had a quadratic relationship with grain yield in this trial (**Figure 3**). Intermediate grain yields had lower grain K concentrations than the lower and higher grain yields.

Summary

The residual effects of K applications to preceding cotton via surface broadcasting on soil K were noticeable, and were strengthened as the K application rate increased. The K rates applied to previous cotton had consistent residual effects on leaf K of subsequent corn during the early to mid-season. Our results suggest that on no-till fields with high K concentrations, surface broadcasting of K fertilizer at the recommended rate of 56 kg K/ha or above to preceding cotton for over 14 years could provide adequate K nutrition for subsequent corn for at least three years without further K fertilization under notillage. Potassium removal by grain ranged from 2.54 to 3.55 kg K/t of corn grain at 15.5% moisture with an average of 3.10 kg K/t of grain, which are lower than the published grain K removal estimates.



Figure 3. Relationship of grain K concentrations with grain yields of corn on the 2009 to 2011 combined data.

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Nutrient Management in Spring Rapeseed-based Systems in the Southern Ural Region

By G.B. Kirillova and G.M. Yusupova

Fertilizer use in the southern Ural region of Russia is inadequate to support attainable yield goals. Improved nutrient management systems readily achieved 80 to 86% of set yield goals for spring rapeseed.

Rapeseed's many uses in products destined for food, oil, forage, and biodiesel have rapidly driven up its production in Russia. Rapeseed crop area has increased by 1.5 times from 2010 to 2013 when it reached its record 1.3 million ha (ROSSTAT, 2014). Spring-sown varieties accounted for 85% of rapeseed's area in 2013, nationally. Our example below from the Russian republic of Bashkortostan, located in the southern Ural region north of Kazakhstan, has shown a similar increase in area seeded to spring rapeseed—reaching 39,000 ha in 2012.

In recent decades, fertilizer use throughout Russia has clearly been low and during the last four years has leveled off at only $39 \text{ kg N+P}_2\text{O}_5 + \text{K}_2\text{O}/\text{ha}$ sown area. Bashkortostan, however, only consumes 50% of this already low national average. This inadequate supply of nutrients can be easily connected to the region's stagnantly low rapeseed yields.

Research in Bashkortostan has been studying the effect of different nutrient management options on rapeseed yield and quality. A three-year field experiment was set up to examine a typical cereal-fodder crop rotation of fallowed green manure (GM), winter wheat, spring wheat, spring rapeseed (cv. Yubileyniy), and silage maize.

The site's soil was fine-textured and the surface layer had medium available P and 'increased' (or elevated) available K (40 to 41 ppm P and 95 to 100 ppm K, respectively)—both extracted with 0.5 M acetic acid solution. The site was located on a typical leached grassland soil classified as a Luvic Chernozem. The soil has relatively high organic matter content (6.8 to 7.2%) and was slightly acidic (pH_{KCl} = 5.2).

The two nutrient management approaches were 1) application of fertilizers and 2) combined application of fertilizers and GM from field pea (**Table 1**). All experiments included a zero-fertilizer (control) treatment and a GM treatment. Treatments 6, 7 and 8 tested the effect of fertilizer application plus GM (third year tested the residual effect of GM). Nutrient application rates were based upon a spring rapeseed yield goal of 2.5 t/ha. Nutrient rates in treatments 2 and 6, 3 and 7, and 4 and 8 were also designed according to a negative (-20 kg P_2O_5 /ha), zero, and positive (20 kg P_2O_5 /ha) P balance. Nitrogen and K rates were based on a zero N balance and a negative K balance (-25 kg K₂O/ha).

Nutrient rates (F) were calculated using a balance method based on an estimated partial nutrient balance (PNB) according to the following formula (Zhukov, 1977):

 $F = (R \div PNB) \ge 100$, where R = nutrient removal (N, P_2O_5 and K_2O) by the targeted seed yield.

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; BMP = best management practice.

Table 1. Effect of nutrient management system on the seedyield of spring rapeseed, Bashkortostan, Russia.								
	2011	2012	2013	Average	Increase			
Treatment			t/ha					
1. Control	2.28	0.81	1.66	1.58	-			
2. N ₁₂₅ P ₄₀ K ₅₀	2.82	1.12	2.04	1.99	0.41			
3. $N_{125}P_{60}K_{50}$	2.80	1.10	2.08	1.99	0.41			
4. $N_{125}P_{80}K_{50}$	3.04	1.14	2.12	2.10	0.52			
5. GM	2.23	0.86	1.79	1.63	0.05			
6. GM + $N_{115}P_{40}K_{50}$	2.90	1.12	2.00	2.01	0.43			
7. GM + $N_{115}P_{60}K_{50}$	2.99	1.16	2.09	2.08	0.50			
8. GM + $N_{115}P_{80}K_{50}$	3.12	1.15	2.16	2.14	0.56			
LSD (0.05)	0.29	0.09	0.19					
LSD (0.05 A)	0.17	0.05	-					
LSD (0.05 B and AB)	0.14	0.05	-					
Note: GM aroon manure (a 3 rd year residual effect): factor A nutri								

Note: GM – green manure (a 3rd year residual effect); factor A – nutrient management system (with or without green manure); factor B – fertilizer rates calculated based on different estimations of P balance; factor AB – interaction between factors A and B.

 PNB_{N} was estimated at 100%; PNB_{p} was 150, 100, and 70% for treatments 2 and 6, 3 and 7, and 4 and 8, respectively (**Table 1**); and PNB_{K} was 150%.

Results

Rapeseed yield fluctuated during the three years and was strongly dependent on the weather (**Table 1**). Weather conditions were quite favorable in 2011 and 2013 as temperatures were close to the long-term average and precipitation was higher than the long-term average. The 2012 season could be characterized as dry and hot with temperatures above the long-term average and monthly rainfall was severely deficient during April, May and July, but excessive in August. In 2012, seed yield was as low as 1.10 to 1.16 t/ha, or 44 to 46% of the yield goal. The best crop year was 2011, which achieved yields of 2.8 to 3.12 t/ha, or 112 to 125% of the yield goal.

Fertilizer application significantly increased seed yield in all years. The highest rates $(N_{125}P_{80}K_{50}$ and $N_{115}P_{80}K_{50})$ resulted in a 0.52 to 0.56 t/ha yield increase (33 to 35%) over the three-years. The highest average yield of 2.14 t/ha (GM + $N_{115}P_{80}K_{50})$ was close to the yield goal, reaching 85% of the target.

In 2012 and 2013, all nutrient management systems achieved a similar relative effect on seed yield. However, the best growing season of 2011 is distinguished by its response to increasing P fertilizer rates up to 80 kg P_2O_5 /ha (the preplanned positive P balance), which increased seed yield to more than 3.0 t/ha. Incorporation of field pea GM into the crop rotation seemed to allow for a N fertilizer rate reduction of 8%

Table 2. Nutrient and crude protein concentration* in springrapeseed seed (2011-2013, Bashkortostan, Russia).									
	Ν	Р	Κ	Crude protein					
Treatment			%						
1. Control	2.74	1.68	0.85	16.2					
2. N ₁₂₅ P ₄₀ K ₅₀	3.34	1.72	0.98	19.4					
3. N ₁₂₅ P ₆₀ K ₅₀	3.33	1.70	0.96	19.5					
4. N ₁₂₅ P ₈₀ K ₅₀	3.38	1.76	1.00	19.8					
5. GM ¹	2.81	1.69	0.87	16.6					
6. GM + $N_{115}P_{40}K_{50}$	3.35	1.72	0.98	19.6					
7. GM + $N_{115}P_{60}K_{50}$	3.36	1.73	0.99	19.7					
8. GM + N ₁₁₅ P ₈₀ K ₅₀	3.38	1.75	1.00	19.8					
*Three-year average expressed on a dry matter basis; ¹ GM = green									

or 10 kg/ha. However, more study is required to optimize N fertilizer rate with or without GM application.

All nutrient management systems increased seed N and K concentrations each season (**Table 2**). Seed N and K concentrations respectively increased by 0.59 to 0.64% and 0.11 to 0.15% due to fertilizer application (three-year average) and reached 3.33 to 3.38% and 0.96 to 1.00% on a dry matter basis. Nutrient management had no significant effect on seed P concentrations in any season.

Nutrient management also impacted crude protein concentrations in all three seasons (**Table 2**). Crude protein increased by 3.2 to 3.6% and reached a maximum of 19.8% (three-year average). Increasing rates of P fertilizer had no affect on crude protein concentration. The highest concentrations of N, P, K, and crude protein were observed in driest and hottest year of 2012.

These results highlight the variable nature of growing season climate in Bashkortostan. Periodic drought can have a significant impact on the yield and quality of rapeseed. Factor analysis of seed yield variability showed that weather and nutrient management accounted for 91% and 7% of the variation, respectively. Nitrogen concentration in seeds was equally dependent on weather and nutrient management. P. The PNB_{N} ranged from 70 to 82%, which is much lower that the 100% value used during the nutrient rate calculations. This difference is related to the actual seed yields obtained in this study, which were lower than the target yield.

Crop demand for nutrients may be estimated based on nutrient removal in the harvested portion of crops and the corresponding amount of straw. In treatments supplying nutrients from fertilizer, the removal of N, P_2O_5 and K_2O (kg/t of seed) increased by 10 to 11, 2, and 7 to 8 kg and reached 52, 25, and 43 kg/t, respectively. Nitrogen and P removal per t of harvested seeds plus straw was close to coefficients normally used for the agroecological zone; however, the removal of K was higher in this study. Thus, removal values need to be updated to properly guide K application rates to meet the yield goals of spring rapeseed.

Three-year averages for agronomic efficiency (AE) of NPK and the contribution of fertilizers to seed yield are also given in **Table 3**. The AE of NPK in fertilizer treatments ranged from 1.74 to 2.04 kg seed/kg $N+P_2O_5+K_2O$ and increased when higher nutrient rates were applied. The contribution of fertilizers to seed yield was between 21 to 26%. All these efficiency parameters tended to be higher under a nutrient management system that included both fertilizers and GM application.

Site-specific nutrient management in the Republic of Bashkortostan supported a yield of spring rapeseed that ranged from 2.00 to 2.14 t/ha, or 80 to 86% of the yield goal. The average crude protein concentration in seeds was also increased to up to 19.8% with balanced fertilization indicating a significant gain in quality.

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Weather conditions accounted for most of the variation in seed P concentration. Nutrient management and weather accounted for 55% and 39% of the variation in seed K concentration, respectively.

Three-year averages for the apparent nutrient balance are presented in **Table 3**. A positive N balance and a negative K balance were observed in all treatments supplying fertilizer nutrients. The P balance was positive for treatments receiving 60 to 80 kg P_2O_5 /ha and were negative under lower rates of fertilizer

Table 3. Nutrient use efficiency in spring rapeseed (2011-2013, Bashkortostan, Russia).								
	Apparent nutrient balance, kg/ha			Pa I	rtial nutri balance, 9	ent %	Agronomic efficiency,	Contribution of fertilization
Treatment	Ν	P_2O_5	K ₂ O	Ν	P_2O_5	K_2O	$N+P_2O_5+K_2O_5$	yield, %
1. Control	-55	-31	-45	-	-	-	-	-
2. N ₁₂₅ P ₄₀ K ₅₀	+38	-1.4	-22	70	104	140	1.91	21
3. N ₁₂₅ P ₆₀ K ₅₀	+37	+19	-21	70	69	138	1.74	21
4. N ₁₂₅ P ₈₀ K ₅₀	+32	+36	-26	75	55	149	2.04	25
5. GM ¹	-50	-28	-51	-	-	-	-	-
6. GM + $N_{115}P_{40}K_{50}$	+31	-6.3	-26	75	105	140	2.00	21
7. GM + N ₁₁₅ P ₆₀ K ₅₀	+28	+16	-27	79	72	145	2.13	24
8. GM + $N_{115}P_{80}K_{50}$	+24	+34	-31	82	57	151	2.20	26
¹ GM = green manure.								

The Fertility of North American Soils: A Preliminary Look at 2015 Results

By T.S. Murrell, P.E. Fixen, T.W. Bruulsema, T.L. Jensen, R.L. Mikkelsen, S.B. Phillips, and W.M. Stewart

The 2015 soil test summary is the fourth in a series of summaries dating back to 2001, 2005, and 2010. For the first time, trends in relative frequencies in soil test levels are being examined.

Preliminary results for Corn Belt states are showing a reduction in percentages of samples testing high in P, but an increase in samples testing low, reflecting a greater need for P fertilization. For K, ranges with the highest percentages of samples, as well as their changes over time, are in general agreement with university recommendations.

Periodically, the International Plant Nutrition Institute (IPNI) summarizes data from public and private soil testing laboratories in North America. Laboratories provide data voluntarily, contributing their own staff time and computing resources. Summaries would not be possible without their generous contributions. This year marks the fourth summary using the same data collection protocol. Previous summaries were conducted in 2001, 2005, and 2010 (Fixen, 2002; Fixen, 2006; Fixen et al. 2010). The 2015 summary is not yet complete, and data continue to be submitted; however, the total number of samples collected for Corn Belt states is already substantially higher than previous summaries (**Table 1**). Until

Table	Table 1.Total number of samples submitted for Corn Belt states as of 31 Oct. 2015.									
	Total numbe	r of samples								
Year	Р	K								
2001	1,207,716	1,137,302								
2005	1,846,736	1,821,570								
2010	2,775,050	2,633,145								
2015	4,285,253	3,951,195								
Note: Corn Belt states are defined in this publication as Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, Ohio, and Wisconsin.										

all data have been submitted, results are considered preliminary and the names of participating laboratories are being withheld.

The protocol distributed to laboratories requested the numbers of samples in various soil test ranges. As in the 2010 summary, data were collected for P, K, S, Mg, Zn, Cl⁻, and pH. Only preliminary data for P and K are presented. A total of 15 categories were used for P and 9 were used for K. Categories were unequal in

width and were right-censored, with the highest category representing samples "greater than" the upper limit of the highest defined interval. Without censoring, a much larger number of categories would have been needed to characterize the few, very high levels characteristic of highly positively skewed soil test distributions.

Different soil test ranges were used for various combinations of extractants and detection methods in an attempt to create equivalency in soil test calibration interpretation. Land Grant University Extension information was used where possible and scientific judgment was used to fill in knowledge gaps. Although equivalencies lacked scientific rigor, the same



equivalencies were used in all summaries, giving credence to examining temporal trends. Because separate summaries were conducted each survey year, laboratory participation and total sample volume varied over time.

Data presented in this publication use a subset of the protocol categories for P. The seven higher categories are grouped into the ">50" category. Data from the "31-40" category in the protocol were divided equally into "31-35" and "36-40" categories. Similarly, data in the "41-50" protocol category were divided equally into the "41-45" and "46-50" categories. These subdivisions were created to make it easier for the reader to visualize the distributions.

In each survey year, laboratories were asked to contribute samples for that year's cropping season rather than within standardized dates to allow for variation in sampling seasons across North America. However, many laboratories chose July



Figure 1. Relative frequencies (left) and average changes in relative frequencies (right) of soil test phosphorus levels from 2001 to 2015, expressed on a Bray and Kurtz P1 equivalent basis, for Corn Belt states and a subset of those states: Illinois, Indiana, and Iowa.

1 of the previous year to June 30 of the survey year as the sampling interval.

Some laboratories were not able to follow the protocol in its entirety. In some cases, a laboratory was not able to definitively associate a sample with a state or province. When this occurred, the state or province assigned to those samples was the one where the majority of the samples was thought to originate.

Additionally, soil test categories provided by the laboratory did not always match those in the protocol. In such cases, data were interpolated into protocol categories.

With the 2015 summary, four sampling periods were available which enabled a more intensive evaluation of trends over



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Figure 2. Relative frequencies (left) and average changes in relative frequencies (right) of soil test potassium levels from 2001 to 2015, expressed on an ammonium acetate equivalent basis, for Corn Belt states and a subset of those states: Illinois, Indiana, and Iowa.

time than has been possible in the past. To examine trends over time, logistic regression was performed for each soil test category, using a linear model. In this analysis, relative frequencies were converted to an odds ratio and that ratio transformed to a logarithmic scale. Because of the large number of samples, used as weights in the regression, the slopes

of all regression models were statistically significant (p-value was 0.05 or less). The difference between 2001 and 2015 log odds ratios, predicted by the regression, was back-transformed to the relative frequency scale and presented as the "average change in percent of samples from 2001 to 2015." Positive values denoted an increase over time.

Results: Phosphorus

Figure 1 shows relative frequencies and average changes in relative frequencies of soil test P levels from 2001 to 2015, expressed on a Bray and Kurtz P1 equivalent basis. Across the Corn Belt as well as for the individual states shown, the largest numbers of samples occurred in the 11-15, 16-20, and >50 ppm ranges. The large percentage of samples in the >50ppm range encompasses data that span a wide range of higher levels representative of a highly positively skewed distribution. The relative frequencies of samples in higher soil test categories, those above 20-25 ppm, have been decreasing. Conversely, relative frequencies of samples testing below 20 ppm have been increasing.

Interpretation of the observed changes is subjective. Reductions in the percentages of samples testing at higher P levels may reflect improved integration of fertilizer and manure management practices over time, reducing over-applications. Increased percentages of P samples testing in lower ranges are not expected, given university recommendations. As an illustration, Indiana, Illinois, and Iowa are states that follow the build and maintenance philosophy. Recommendations are to build soils to levels where only moderate to low probabilities of yield response to P additions exist and, once there, maintain them. Maintenance ranges for corn and soybean production for each of these states are: Illinois, 20-35 ppm (Fernández and Hoeft. 2015); Indiana, 15-30 ppm (Vitosh et al., 1995); and Iowa, 16-20 ppm. If fertility were being managed according to these recommendations, relative frequency decreases, rather than increases, would be observed for these lower soil test ranges. A possible explanation is that over time, greater use of grid and zone sampling has revealed low testing areas previously unidentified when more traditional practices of sampling larger areas were followed. Regardless of the causes, the increases in percentages of samples in low soil test P ranges mean the identified need for P fertilization is increasing.

Results: Potassium

Figure 2 shows results for K expressed on an ammonium acetate equivalent basis. In 2015, the Corn Belt states considered as a group had the largest percentages of K samples in the 81-120, 121-160, and 161-200 ppm ranges, and the percentages of samples among these ranges have been increasing the most. Percentages in lower categories have been decreasing, as have percentages in the >320 ppm category. These are in general agreement with university recommendations in this region.

Illinois had the largest number of 2015 samples in the 121-160 and 161-200 ppm ranges. Over time, percentages of samples decreased above and below these ranges. These observations are consistent with Illinois' recommendation to build soils to the 130-200 ppm range and maintain them there.

In Indiana, the largest percentage of 2015 samples were in the 81-120, 121-160, and 161-200 ppm ranges, also in agreement with university recommendations to build and maintain soils in the 88-180 ppm range (Vitosh et al., 1995). These recommendations have been in place during all soil test summary years, and this consistency is likely reflected in the small changes over time in each soil test category.

Iowa has seen more marked changes over time. Iowa State University has revised its K recommendations two times during the span of the soil test summaries. In 2002, the recommended maintenance range for soils with low subsoil K (the majority of Iowa soils) was increased from 91-130 to 131-170 ppm (Sawyer et al., 2002; Voss et al., 1999). In 2013, the maintenance range was further increased to 161-200 ppm (Mallarino et al., 2013). In 2015, the highest percentages of samples were in the 121-160, 161-200, and 201-240 ppm ranges. Increases in percentages of samples over time have occurred in soil test categories above 160 ppm, with concomitant decreases occurring at or below that level. Directionally, these changes are in agreement with the changes made in university recommendations over time; however, the increases in sample percentages in higher categories, above 240 ppm, may reflect nutrient management approaches that differ from those recommended by the university.

Summary

The 2015 soil test summary is the fourth in a series of summaries conducted by IPNI. For the first time, changes over time were analyzed. More samples continue to be submitted to the summary, but preliminary results indicate that for Corn Belt states, lower percentages of samples are testing high in P while larger percentages are testing low, indicating a growing need for P fertilization. For K, soil test levels and their changes are generally in agreement with university recommendations.

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CUTTING THROUGH THE NOISE

Trecently came across news of a national U.S. survey that confirmed to me that most of the general public has only a poor understanding of basic scientific concepts. Perhaps this is understandable because we are seemingly bombarded with "sound-bite" information from every direction.

Perhaps fundamental science education doesn't get enough attention in the classroom. But our society is forced to filter a flood of media messages that often come served with an agenda. Without a grasp of basic science principles mixed with common sense, it is easy to be swayed by any slick



presentation. I am frequently dismayed when poor or inaccurate science related to plant nutrition is held up as "fact."

While it is not necessary for everyone to know the details of potash mining or the chemical reactions involved in phosphate fertilizer production, they should be able to understand that you can't get something from nothing. Plants always require the basic components of growth from the soil in order to thrive. The inescapable link between well-nourished plants and healthy food should be evident to everyone.

The central mission of IPNI is to "develop and promote scientific information for the responsible management of plant nutrition for the benefit of the human family." We have no commercial agenda or any scientific slant other than to develop and deliver the best information on responsible nutrient management. The title of this magazine, "*Better Crops with Plant Food*", conveys one attempt to achieve this goal.

We remain committed to delivering the very best science-based information. How the message is delivered changes over time, but the mandate remains the same: feeding a hungry world with abundant and nutritious food can only be done with responsible nutrient use. We will continue to provide science-based information and will work to keep you up-to-date on the latest developments in plant nutrition science. Let's work together to help people appreciate the vital role of plant nutrients in producing a sustainable food supply.

BETTER CROPS

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