BETTER CROPS
WITH PLANT FOOD

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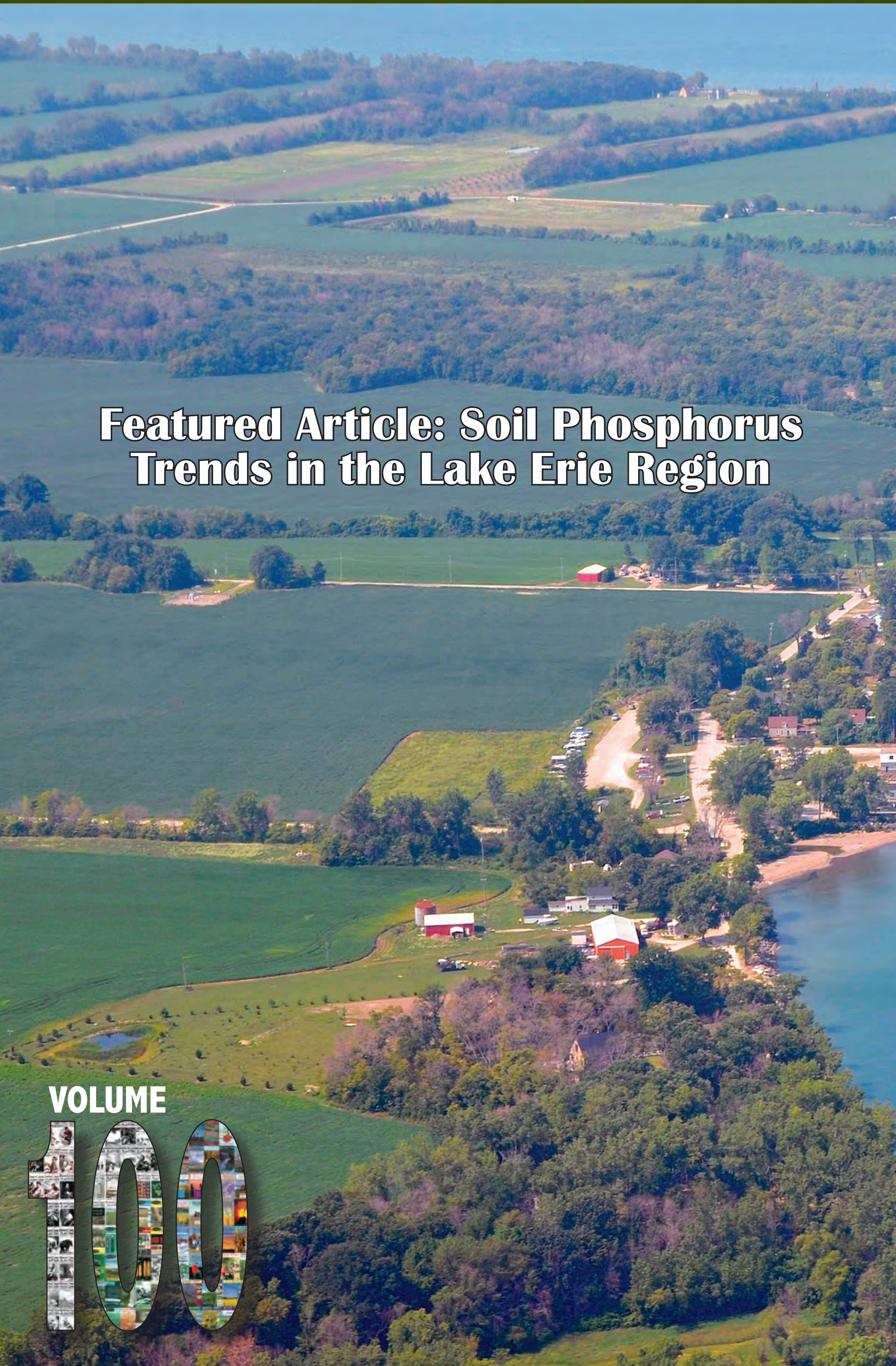

Featured Article: Soil Phosphorus Trends in the Lake Erie Region

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Getting Current with P and K Responses in Ohio

Can N Management be Improved for Sunflower?

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Also:

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...and much more

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BETTER CROPS WITH PLANT FOOD

Vol. C (100) 2016, No. 2

Our cover: Farmland on Pelee Island, Ontario, bordering Lake Erie.
Photo by: SkyF @iStock
Editor: Gavin D. Sulewski
Assistant Editor: Sharon Jollay
Design: Rob LeMaster
Back page illustration: Greg Cravens

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

IPNI thanks the Government of Saskatchewan for their support of this publication through its resource tax funding.

International Conference on the Frontiers of Potassium Science January 25-27, 2017 – Sheraton Roma in Rome, Italy

IPNI is pleased to invite you to participate in the upcoming international conference designed to exchange information on how to improve potassium plant nutrition and soil management to better the health of soils, plants, animals, and humans. The 4R Nutrient Stewardship framework is integrated into the conference structure to keep the discussions anchored to the information needs of farmers and those who provide nutrient management guidance.

Sign up to get regular updates, including when and how to submit your abstract, at http://KFrontiers.org. Submissions addressing the questions below will be given priority and will be considered for inclusion in a special peer-reviewed publication following the conference. We look forward to seeing you in Rome!

Potassium in Sustainable Intensification of Cropping Systems

- How do potassium inputs and outputs compare for different cropping systems and geopolitical boundaries?
- How and to what extent does potassium affect use efficiency of water, energy, and other nutrients?
- How and to what extent does potassium mitigate biotic and abiotic stresses on plants?
- What conditions favor loss of bioavailable potassium and how much is lost?
- What can long-term research experiments teach us about potassium management?
- What are the current, key issues in human and animal potassium nutrition?

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

- What are the lifetimes of the various global reserves of potassium?
- How are crops impacted (positively/negatively) by the choice of potassium source?
- How does the source of potassium fertilizer affect its proper placement in the soil?
- To what extent does potassium source impact plant recovery efficiency of potassium?

4R Rate: Improving the accuracy of potassium rate recommendations

- How can we improve the quantification of plant-available potassium in the soil?
- How can we improve approaches to making potassium rate recommendations?
- How can cycling of potassium from crop and other organic residues be integrated into potassium rate recommendations?
- How closely is potassium mass balance related to soil test changes?
- Why and to what extent do various crops differ in their recovery efficiency of potassium?

4R Time: Improving decisions about when to apply potassium

- What are the genetic effects on potassium accumulation rates, partitioning, and plant metabolism?
- How can potassium be managed to improve the synchrony of soil supply and plant demand?
- What is the potassium recovery efficiency of the cropping system as a whole, considering the crops grown and when applications are made?

4R Place: Improving potassium placement decisions

- What plant characteristics (rhizosphere biology and chemistry, root architecture, etc.) most influence potassium placement decisions?
- What soil characteristics (physical, chemical, biological) most influence potassium placement decisions?
- To what extent does nutrient placement impact plant recovery efficiency of potassium?

Connecting Frontier Science to Frontier Practice

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

Soil Phosphorus Trends in the Lake Erie Region

By Tom Bruulsema

Over the past 15 years, increasing loads of dissolved P into Lake Erie have focused attention on agriculture in its watershed.

During the same time period, soil test P levels have declined. Fewer soils now test at extremely high P levels, and nearly half test at levels where crop yields depend directly on annual P application.

Opportunities to contribute to P load reductions for Lake Erie include better directing P applications to the soils testing below the optimum range, better timing and placement, and improved integration with other conservation practices in a complete 4R Nutrient Stewardship approach.

iStockphoto/SkyF

Bigger harvests from cropland near Lake Erie have led to lower levels of soil test P. Photo of farmland near Leamington, Ontario.

Recent trends in algal blooms in Lake Erie have focused considerable attention on P losses from agriculture in its watershed. The lake's western basin has been the most affected. Considerable portions of the cropland in Ohio, Indiana, Michigan, and Ontario drain into the western basin. Tributary monitoring has shown increasing trends in the load and concentration of dissolved P from the mid-1990s to the present, particularly for the March through July period. The causes of the increasing trend are not yet fully understood, but since agriculture occupies the majority of the watershed and cycles large amounts of P, it is receiving considerable attention.

Abbreviations and notes: P = phosphorus; CEAP = Conservation Effects Assessment Project; USDA-NRCS = United States Department of Agriculture, Natural Resources Conservation Service.

The 2015 soil test summary by the International Plant Nutrition Institute (IPNI) was the largest ever conducted (IPNI, 2016). Thus data are available and presented here for the distribution of soil test P in these four jurisdictions. **Figures 1a** and **1b** shows the results and trends for relative frequencies of soil test P. These are based on a compilation of all samples submitted to the public and private laboratories that participated in the summary. The number of samples increased over time, largely due to increased frequency and intensity of soil sampling. Representation of the land area is not perfect, however, since some farmers sample more intensively than others. The 2012 CEAP survey of the U.S. portion of the watershed estimated that 71% of the cropland had soil nutrient tests taken in the past five years (USDA-NRCS, 2016).

Several different soil test methods are widely used across the region. Many producers and commercial laboratories use the Mehlich-3 method. To provide comparability over the region, all soil test levels were converted to the Bray and Kurtz P1 soil test, which is the one used as the basis for the region's tri-state soil fertility recommendations. The maintenance range, which can be considered optimum, is 15 to 30 ppm for corn and soybeans, and 20 to 40 ppm for alfalfa and wheat. Soil fertility recommendations in the province of Ontario are based on the Olsen soil test. While Ontario's sufficiency-based recommendations differ from the "build and maintain" approach used in the tri-state region, critical levels are roughly similar.

In each of the four jurisdictions, the frequency of soils testing in the 0 to 15 ppm range increased. Pooled together over the region, the percentage of the soils that were below the lowest critical level increased from 13% in 2001 to 28% in 2015. In addition, yield of some crops could be P limited in the 16 to 25 ppm range as well, which increased from 19 to 22% over the same time period. Thus, currently, P would be expected to limit yields of some crops, if none were applied, on half the cropland in these four jurisdictions.

Concurrent with the increase in soils testing below critical levels, the frequency of soils testing considerably higher than optimum (above 50 ppm) declined from 36 to 26% overall. This represents a reduction of risk to water quality, and is not a threat to crop productivity. The decline was particularly prominent in Michigan and Ontario. It possibly reflects success in nutrient management efforts by livestock operations over the past few decades.

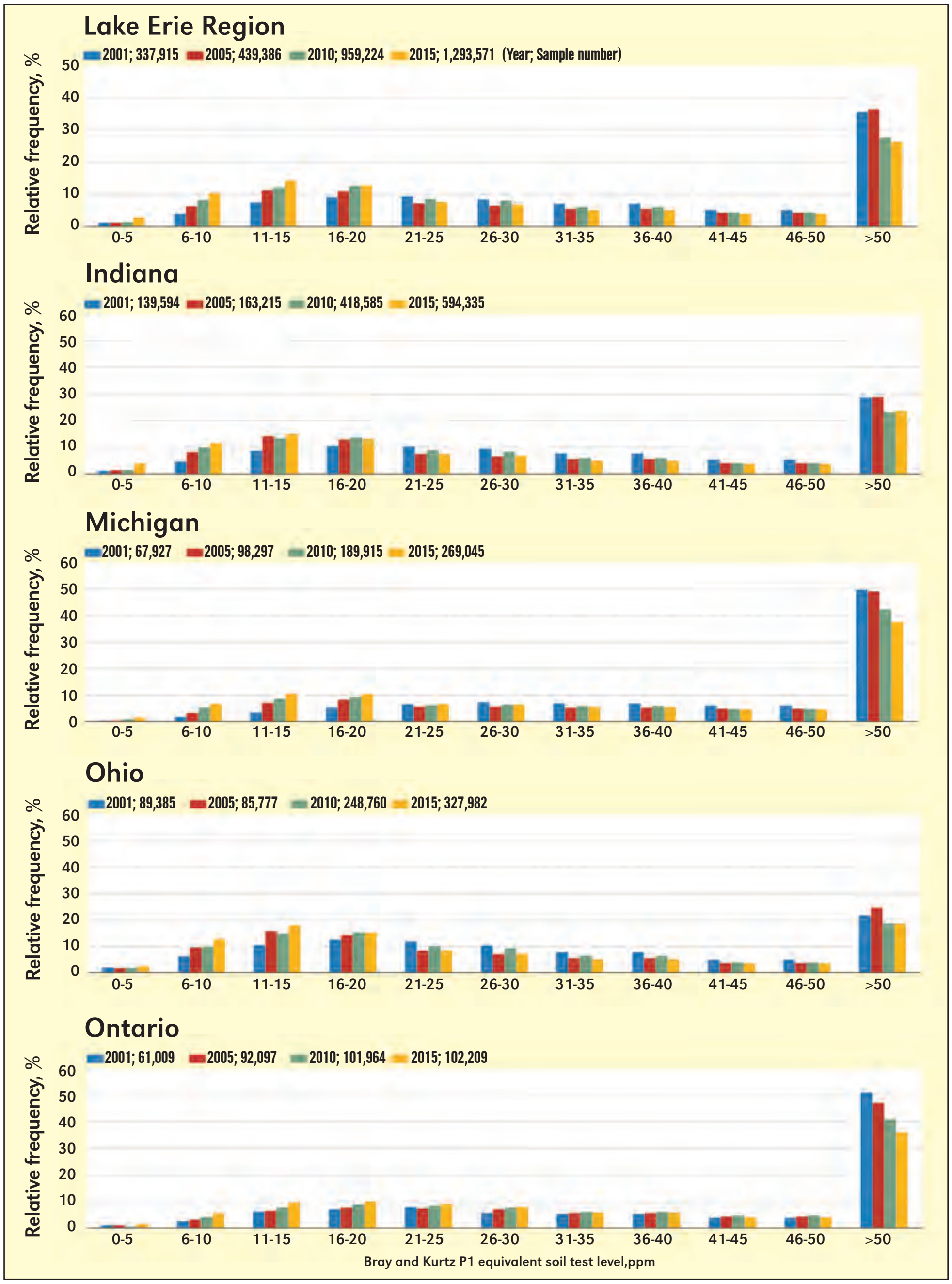

Figure 1a. Relative frequencies of soil test P levels from 2001 to 2015, for the province and three states with substantial drainage into Lake Erie.

The changes in soil test P levels are consistent with changes in the cropland P balance (**Figures 2** and **3**). During the 1970s and 1980s, cropland P balances were in surplus, as indicated for 1987. Over time, with increasing crop yields and removal of P with harvest, surpluses have diminished and deficits have increased. The 2012 CEAP survey found that 58% of cropland acres were managed with P application rates at or below crop removal rates (USDA-NRCS, 2016). Ontario cropland receives a greater proportion of its P inputs as manure than the cropland of the Lake Erie basin in the U.S.; thus, the priorities for reducing risks of P loss to water may differ between these jurisdictions to some extent.

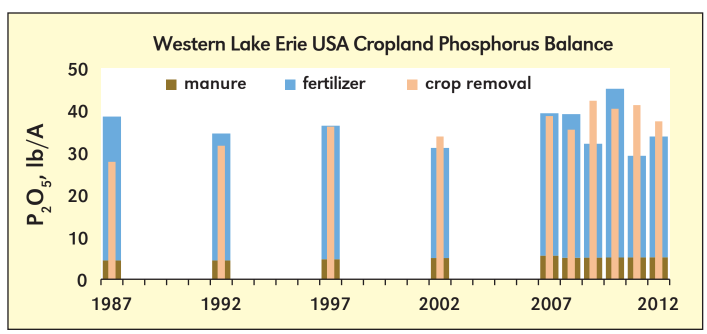

Figure 2. Partial balance for cropland P in the western Lake Erie basin, including the Maumee, Sandusky, Raisin, and Cedar-Portage river watersheds. Inputs include fertilizer and manure applied; output is crop removal estimated from reported yields. NuGIS, 2016.

Given the declining trend in soil test P and cropland P balance, one might assume little opportunity for crop P man-

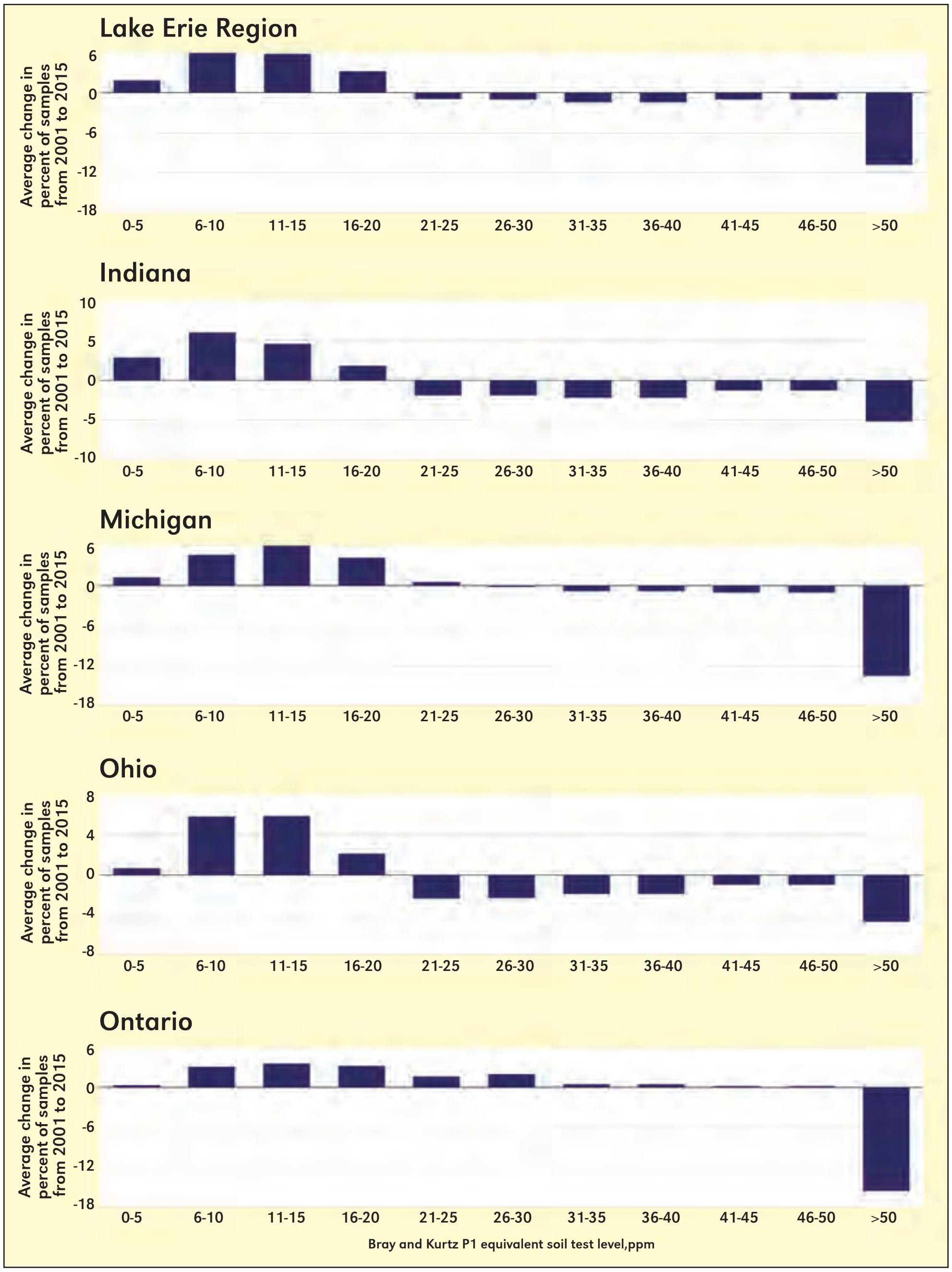

Figure 1b. Average changes in relative frequencies from 2001 to 2015, for the province and three states with substantial drainage into Lake Erie.

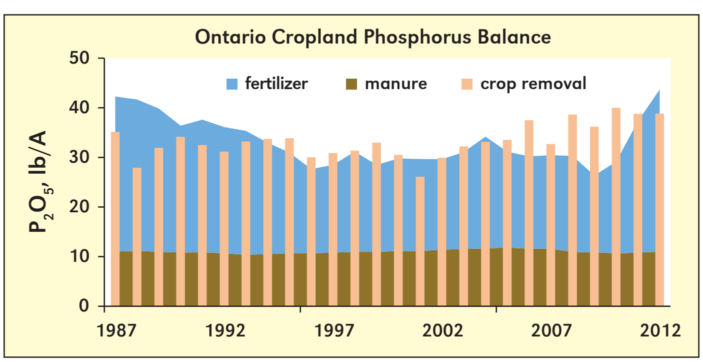

Figure 3. Partial balance for cropland P in Ontario, Canada. Inputs include fertilizer and manure applied; output is crop removal estimated from reported yields, using methods similar to those in NuGIS (2016) and Bruulsema et al., (2011).

agement to contribute to reductions in P losses to water. This is not true. Several important opportunities are only partially revealed in these data.

1. Currently only 38% of soils test in the optimum range of 15 to 40 ppm. There is clear opportunity to better direct more of the current P applications to the 28% of soils that test below the optimum range, and less to the 33% that test above.
2. Placement and timing of P applications could be improved. In 2012, 40% of the cropland received P applications that were neither incorporated, nor subsurface banded, nor injected. Application in winter, between November and February, accounted for 13% of the P applied (USDA-NRCS, 2016).
3. These soil test summary results do not address the issue of P stratification. In conservation-tilled and no-till systems, the top inch of soil can become enriched to as much as three times the level in the recommended sampling depth. Since the P concentration of drainage water is influenced by the concentration of P in the top inch, managing stratification with techniques such as strip tillage offers opportunity to apply P with less loss to water.
4. Additional conservation practices such as drainage water management and cover crops to improve water retention in the soil offer opportunity to maintain or improve crop yields while reducing potential P loss.

The Great Lakes Water Quality Agreement Nutrients Annex has recommended a target to reduce P loadings to Lake Erie by 40% relative to 2008. This very challenging target will not be achieved with P application practices alone. Nevertheless, integration of conservation practices with P application practices in a complete 4R Nutrient Stewardship approach offers opportunity for crop producers, their advisers, and the crop nutrition industry to do their part. BC

Dr. Bruulsema is Director, IPNI Phosphorus Program, Guelph, ON, Canada. E-mail: tombruulsema@ipni.net

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Corn and Soybean Response to Phosphorus and Potassium Fertilization in Ohio

By A.M. Fulford, S.W. Culman, R.W. Mullen, C.E. Dygert, G.A. LaBarge, E.M. Lentz, and H.D. Watters

The most recent fertilizer P and K rate recommendations for corn and soybeans grown in Ohio were last updated in the mid-90s.

Research is needed to verify the appropriateness of these recommendations after 20 years.

This study found that corn and soybean yield response frequencies to P and K fertilization did not differ much from expectations based on initial soil test levels, but greater than expected soil test declines call for further research.

Maintaining or building soil fertility can be influenced by soil test trends that become apparent only after years of crop production. Results from nearly 30 years of corn and soybean production have been used to document the buildup, maintenance, or decline of soil P as influenced by initial soil test P (McCollum, 1991; Dodd and Mallarino, 2005). Long-term nutrient budgets have also been developed from over 30 years of corn and soybean production to assess the soil balance of P and K in the U.S. (Fixen and Murrell, 2002; Bruulsema et al., 2011).

In Ohio, P and K fertilizer recommendations for corn and soybeans follow the buildup, maintenance, and drawdown approach outlined in the, "Tri-State Fertilizer Recommendations for Corn, Soybeans, Wheat and Alfalfa" (Vitosh et al., 1995). This publication has served as a cornerstone for field crop soil fertility in the region, but after 20 years, a re-examination of these fertility recommendations is necessary, as a number of factors have changed in field crop production. In this study, fertilizer P and K application rates estimated to equal or exceed crop removal were applied and resulting corn and soybean grain yield and soil test P and K trends were observed throughout nine years of production at three sites in Ohio.

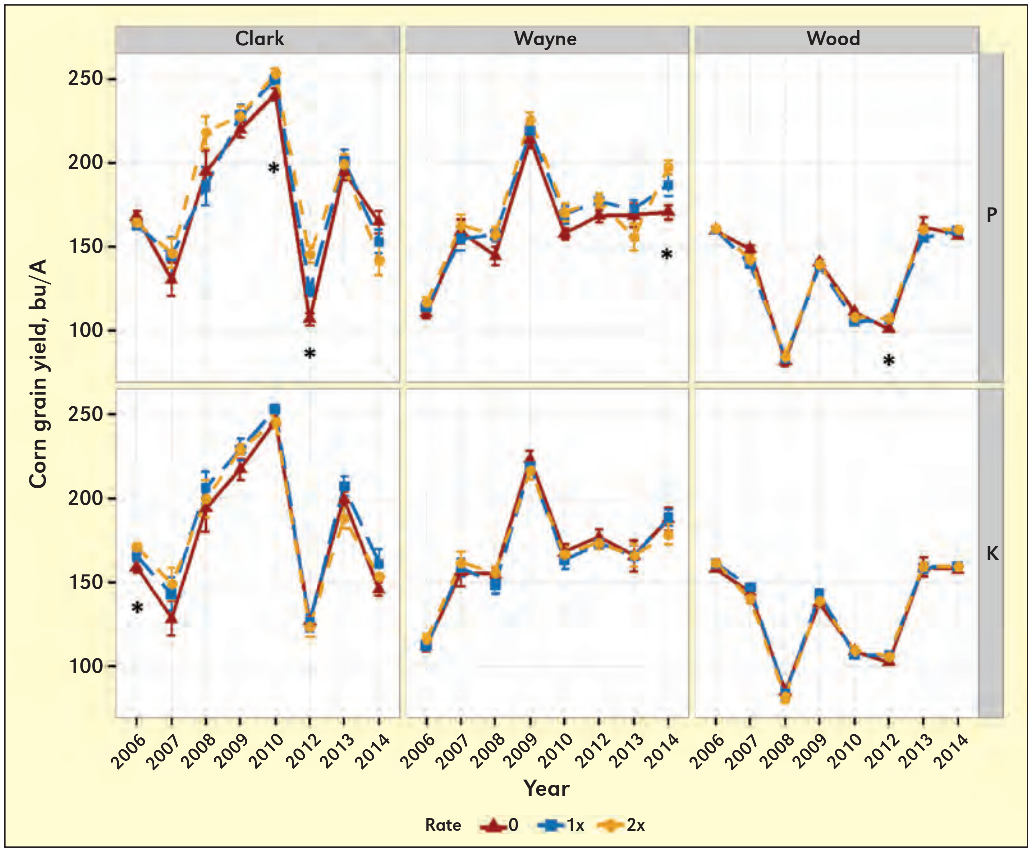

Figure 1. Corn grain yield response to P or K fertilizer applied at 0, 1x, and 2x the estimated crop removal rate for Clark, Wayne, and Wood county sites in Ohio. Asterisk denotes a significant ($p < 0.05$) grain yield increase compared to unfertilized (0 lb/A P_2O_5 or 0 lb/A K_2O) corn. All error bars denote standard error of the mean.

The study was initiated in 2006 in Clark, Wayne, and Wood counties in Ohio and continued until 2014. At all sites, corn-soybean (CS) and corn-corn-soybean (CCS) rotations were established and subsequently managed according to the phase of each cropping sequence. The total fertilizer N rate applied to corn was 180 lb N/A following soybean and 210 lb N/A following corn.

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium. IPNI Project USA-OH16.

Fertilizer P and K was applied based on the estimated nutrient removal of each crop rotation. The 2005 Ohio statewide average corn (145 bu/A) and soybean (40 bu/A) yields were multiplied by the Tri-State Fertilizer Recommendations estimated crop removal, in pounds of nutrient per bushel (0.37 and 0.27 for P_2O_5 and K_2O for corn; 0.80 and 1.4 for P_2O_5 and K_2O for soybeans, respectively; Vitosh et al., 1995). Therefore, the respective 1x and 2x fertilizer rates for CS were 85 and 170 lb P_2O_5/A, and 95 and 190 lb K_2O/A, while the respective 1x and 2x fertilizer rates for CCS were 140 and 280 lb/A for both P_2O_5 and K_2O. Phosphorus was supplied as triple superphosphate or diammonium phosphate and K was supplied as potassium chloride. Initial P and K fertilization occurred in fall 2005 (Wood County) or spring 2006 (Clark and Wayne counties) and subsequent P and K fertilization followed soybean harvest for both rotations.

Soil samples were collected from each site in the fall prior to broadcast and surface incorporation of P and K fertilizer. Grain yield was measured for each crop in the rotation and soil test P (i.e., Bray P1) and K (i.e., ammonium acetate extractable-K) were measured for each site. Soil test levels were interpreted with respect to the maintenance range for plant-available P and K for corn and soybeans grown in Ohio (Vitosh et al., 1995). For each rotation, only one crop within that rotation (i.e., one entry point) was present for any given year. In other words, 2006, 2010, and 2012 were corn years for CS and CCS; 2011 was a soybean year for CS and CCS. The influence of crop rotation on grain yield was evaluated in these four (out of nine) years but was not significantly different between rotations. Accordingly, grain yields were averaged across crop rotations for these years.

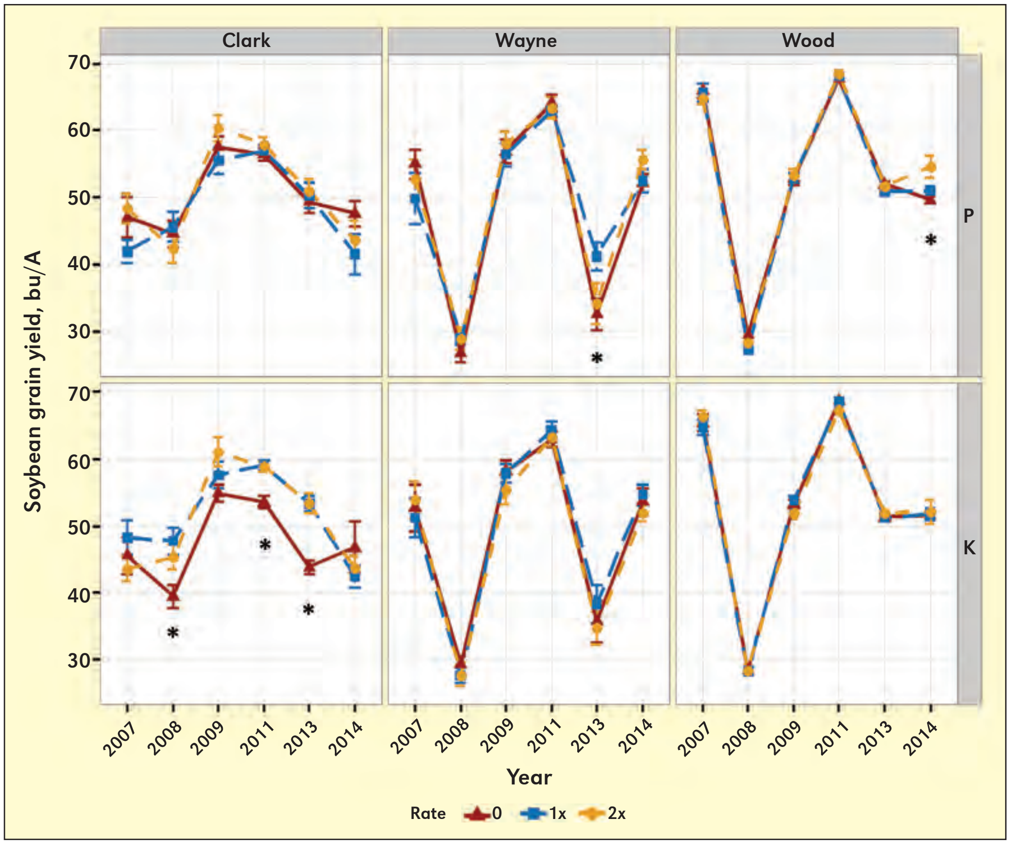

Figure 2. Soybean grain yield response to P or K fertilizer applied at 0, 1x, and 2x the estimated crop removal rate for Clark, Wayne, and Wood county sites in Ohio. Asterisk denotes a significant ($p < 0.05$) grain yield increase compared to unfertilized (0 lb/A P_2O_5 or 0 lb/A K_2O) soybeans. All error bars denote standard error of the mean.

Corn and Soybean Yield

Corn grain yield exhibited a significant positive response to P fertilization in four of 24 site-years, while corn yield increased significantly with K fertilization in one of 24 site-years (**Figure 1**). A positive response to P fertilization occurred in 2010 (Clark County), 2012 (Clark and Wood counties), and 2014 (Wayne County) as corn yield increased by as much as 13, 39, and 27 bu/A, respectively. Phosphorus fertilization significantly increased soybean yield in two of 18 site-years and grain yield increased by as much as 9 bu/A at Wayne in 2013 and by up to 5 bu/A at Wood in 2014 (**Figure 2**). Soybean grain yield was significantly increased by K fertilization in three of 18 site-years as yield increased by as much as 9, 5, and 9 bu/A at Clark in 2008, 2011, and 2013, respectively. (Respective corn and soybean yields averaged across nine years were: Clark, 182 and 51 bu/A; Wayne, 163 and 51 bu/A; Wood, 130 and 55 bu/A). Across years, fertilizer P and K rates applied in combination did not significantly influence the grain yield of corn ($p = 0.72$) or soybeans ($p = 0.58$).

Table 1. Nine-year nutrient balance (nutrient applied - nutrient removed, lb/A) of corn-corn-soybean (CCS) and corn-soybean (CS) rotations at Clark, Wayne, and Wood county sites.

		- - Clark - -		- - Wayne - -		- - Wood - -	
Nutrient	Fertilizer Rate	CCS	CS	CCS	CS	CCS	CS
		- - - - - - - -	- - - - - - - -	- - - lb/A - - -	- - - - - - - -	- - - - - - - -	- - - - - - - -
Phosphorus	1x	-90	-38	-57	-37	8	8
	2x	339	340	350	384	418	439
Potassium	1x	-82	-97	-42	6	4	-14
	2x	356	439	393	447	413	449

Cumulative nutrient applied for the respective 1x and 2x fertilizer rates for CCS were: 420 and 840 lb/A for both P_2O_5 and K_2O; while the respective 1x and 2x rates for CS were: 425 and 850 lb P_2O_5/A, and 475 and 950 lb K_2O/A. Grain yields of CCS and CS rotations were used to estimate cumulative nutrient removal.

Soil Test Phosphorus and Potassium Levels

Nine-year soil test P levels appeared to decline more rapidly for CCS at Clark and Wayne compared to Wood (**Figure 3**). Soil test P decreased from initial levels in 2006 for CCS, despite P fertilization at a 1x rate, by as much as 9 ppm for Wood and by as much as 21 and 18 ppm for Clark and Wayne counties, respectively. This trend is consistent with yields averaged across years at these sites, as Clark and Wayne yielded more than 145 bu corn/A and 40 bu soybean/A, while Wood yielded less corn. The nine-year trend of soil test K appeared to decline at each site for both rotations regardless of fertilizer K rate (**Figure 4**). Soil test K decreased from initial levels in 2006 for the respective 1x and 2x fertilizer K rates by an average of 30 and 19 ppm for CS and by 32 and 25 ppm for CCS.

Declining trends of soil test P and K regardless of fertilization calls into question estimated crop removal rates and the soil test level response. The nine-year nutrient balance of the 1x fertilizer rate indicated a deficit of 97 lb/A or less, while the 2x fertilizer rate resulted in a nutrient surplus ranging from 339 to 449 lb/A across sites and rotations (**Table 1**). This raises two (or more) questions which should be addressed in future research: 1) *Do current estimated nutrient concentrations in*

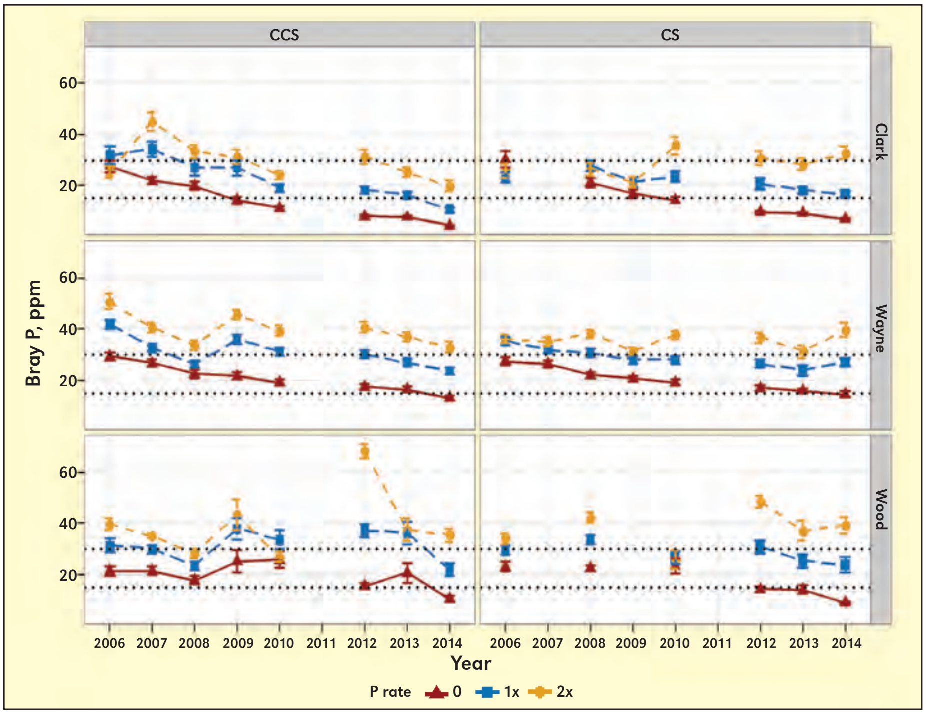

Figure 3. Soil test P (Bray P1) trends for two corn and soybean rotations (CS or CCS) in response to P fertilizer applied at 0, 1x, and 2x the estimated crop removal rate for Clark, Wayne, and Wood county sites in Ohio. Dotted lines represent the maintenance range for each site.Fertilizer was initially applied in fall 2005 (Wood) or spring 2006 (Clark and Wayne) and then following soybean harvest in 2008 and 2011 for CCS or 2007, 2009, 2011, and 2013 for cs. All error bars denote standard error of the mean.

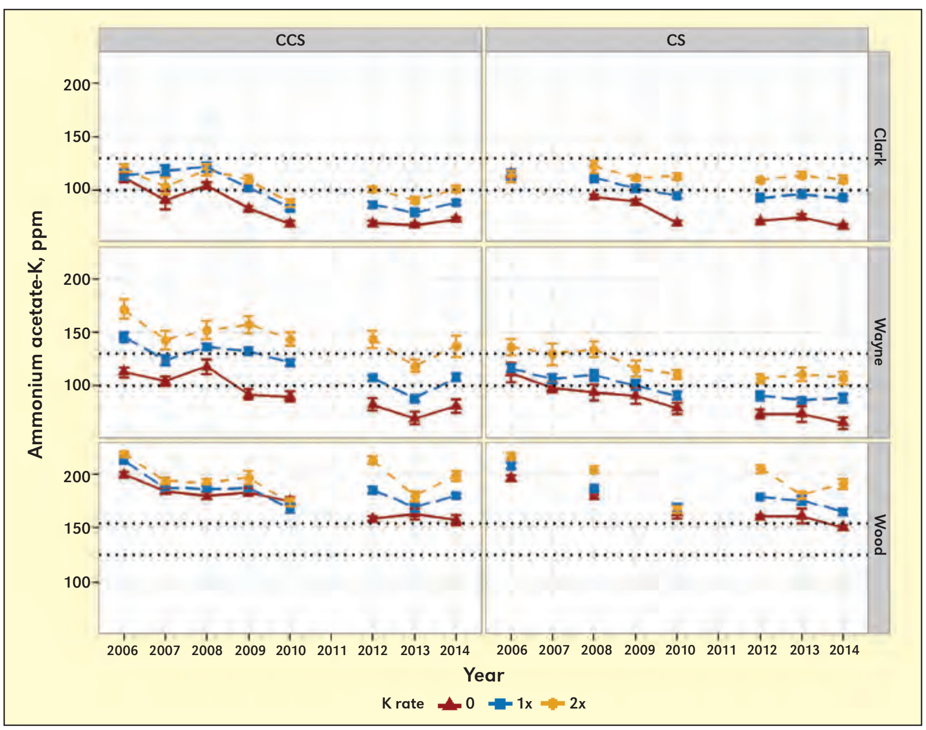

Figure 4. Soil test K (ammonium acetate extractable-K) trends for two corn and soybean rotations (CS or CCS) in response to K fertilizer applied at 0, 1x, and 2x the estimated crop removal rate for Clark, Wayne, and Wood county sites. The dotted lines represent the upper and lower limits of the maintenance range for each site. Fertilizer was initially applied in fall 2005 (Wood) or spring 2006 (Clark and Wayne) and then following soybean harvest in 2008 and 2011 for CCS or 2007, 2009, 2011, and 2013 for CS. All error bars denote standard error of the mean.

corn and soybean grain accurately reflect what is removed? and 2) *Are soil test P and K levels relatively stable from year to year if the amount of nutrient applied approximates the quantity of nutrient removed?*

Summary

In Ohio, soils with P and K initially testing within recommended maintenance ranges exhibited positive corn and soybean yield responses to P and K fertilization in 10 of 42 site-years. Results from 24 site-years of corn production indicated 17% and 4% of site-years responded positively to P and K fertilization, respectively. Results from 18 site-years of soybean production revealed a positive response to P and K fertilizer application in 11% and 17% of site-years, respectively. The response frequencies to P and K fertilization suggest the current maintenance ranges for soil test P and K are not too low and reflect the expected odds of a yield response to P and K for corn and soybeans grown in rotation. However, questions remain about observed soil test P and K downward trends, despite application of P and K fertilizer at two times the estimated crop removal rate. BC

Drs. Fulford, Culman, Dygert, LaBarge, Lentz, and Watters are with The Ohio State University, Columbus, Ohio; E-mail: fulford.19@osu.edu. Dr. Mullen is with the Potash Corporation of Saskatchewan, Saskatoon, Saskatchewan.

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Can We Improve Nitrogen Management for Sunflower?

By N. Diovisalvi, N. Reussi Calvo, G. Divito, N. Izquierdo, H.E. Echeverría, and F. García

The correct diagnosis of soil N availability for sunflower is critical to deciding the right N rate for maximum seed yield and adequate oil and protein concentration.
Use of local sensors to characterize in-crop N status will complement any soil N diagnosis.

Nitrogen is the main nutrient that affects yield and seed quality of sunflower. Oil concentration determines the commercial quality of the seeds, while protein concentration is key to sunflower by-products. Increases of 1% in seed protein would generate increases of up to 5% in by-products. Nitrogen deficiency decreases leaf area and photosynthetic rate, and consequently radiation interception and use efficiency (Massignam et al., 2009). Adequate soil N availability is necessary to achieve high oil and protein concentration in the seeds; however, excessive levels can decrease the percentage of oil. Therefore, accurate N diagnosis methods are needed.

The most widely used diagnostic method for N in Argentinian sunflower is based on determining N availability at planting (NA), which includes pre-plant soil nitrate-N (NO_3-N) at 0 to 60 cm depth (PPSNT) plus fertilizer N (FN). Several critical thresholds have been proposed to maximize seed yield and define the production and economic optimum NA (i.e., PONA and EONA). However, NA has low predictive performance in regions with excessive water, before or after sampling, because of nitrate leaching losses. Furthermore, this method does not consider the contribution of N by mineralization during the growing season. Under a similar situation, the soil nitrate-N test at the 6-leaf stage (6-leaf SNT) has been proposed for maize (Magdoff et al., 1984), although this method does not define the economic optimum N rate.

Soil N diagnosis could be complemented with sensors measuring transmittance (Minolta SPAD 502®) and reflectance (GreenSeeker®), which might characterize the N status of the crop at 6-leaf and 12-leaf stages (V6 and V12, Schneiter and Miller, 1981). While both sensors have been successfully tested in different crops (wheat, corn, potatoes, etc.), no information is available for sunflower. The Minolta SPAD 502 sensor determines leaf greenness (LG) while the GreenSeeker sensor determines a vegetation index (NDVI). As these sensors are affected by several factors (genotype, management conditions, etc.), it is recommended to relativize the measurements with reference areas without N limitation, defining an N sufficiency index (NSI) for the Minolta SPAD 502, and a relative NDVI (NDVIr) for the GreenSeeker.

This article outlines a series of field experiments that: 1) evaluate the effect of N on seed yield and protein and oil concentration, 2) assess the predictive performance of NA, 3) determine the PONA and EONA, and 4) evaluate the predictive performance of N diagnosis methods based on determining the NSI and NDVIr.

Abbreviations and notes: N = nitrogen.

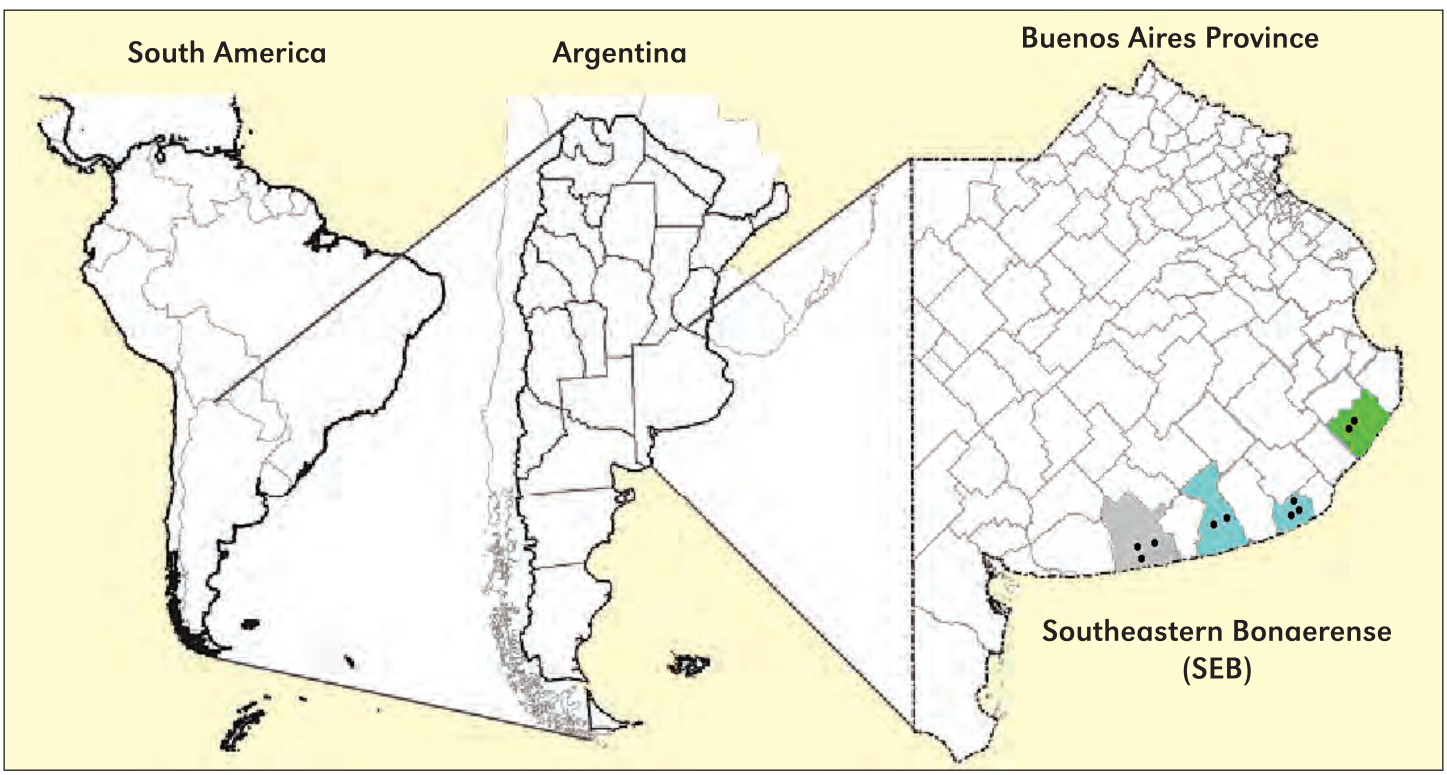

Figure 1. Location of sunflower experimental sites in the 2014-15 season. Green area: Gral. Madariaga. Blue area: Miramar-Mechongué-Necochea. Grey area: Tres Arroyos.

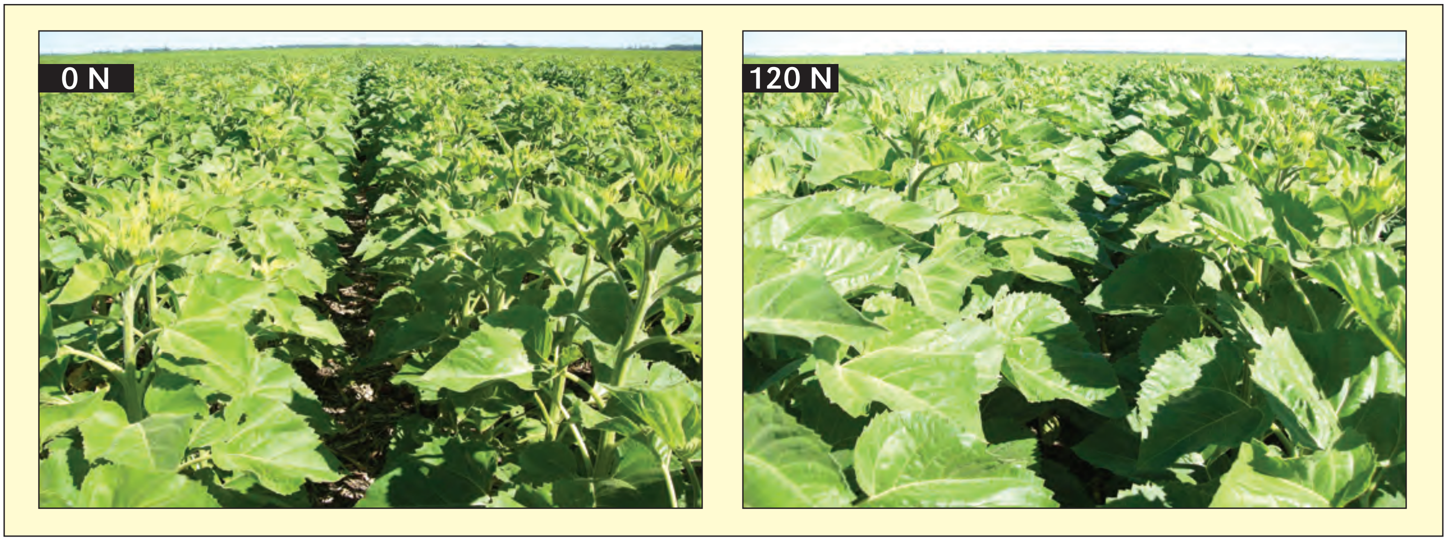

Figure 2. Plots without N application (left) and with 120 kg N/ha (right).

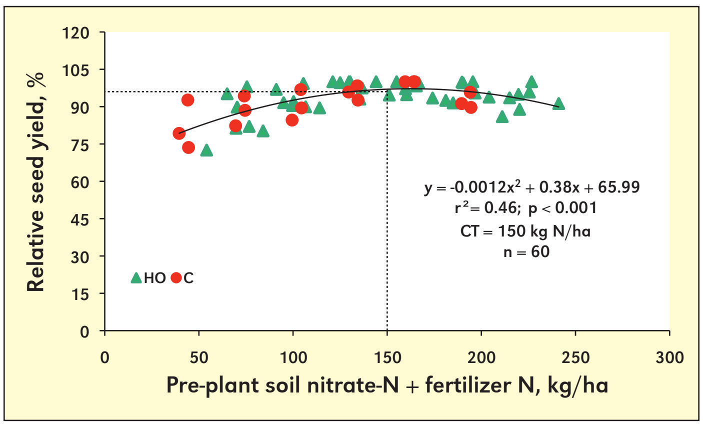

Figure 3. Relative seed yield (RSY) as a function of N availability at planting. CT = critical threshold for 95% RSY. HO = high oleic hybrids. C = conventional hybrids. n = number of cases.

Field Experiments

During the 2014-2015 season, 10 N fertilization experiments were carried out in southwestern Buenos Aires province (Argentina), evaluating N rates (0 to 120 kg N/ha), under environments with different soil and weather conditions (**Figure 1**). The predominant soils are prairie soils without and with a calcareous layer, with sandy loam to sandy clay loam texture. Soil Bray P1, organic matter, and pH (0 to 20 cm) were 12.4 ± 4.0 mg/kg, 5.1 ± 1.2%, and 5.9 ± 0.3, respectively. Sunflower genotypes include high oleic (HO) (n = 7), and conventional (C) (n = 3) hybrids.

Seed Yield and Quality

Average seed yield was 3,540 ± 484 kg/ha and N response 590 ± 208 kg/ha. Seed yield responses to N were significant at five sites. Nitrogen fertilization increases leaf area development, which resulted in an increase in radiation interception by the crop (**Figure 2**).

The HO hybrids had lower percentages of oil and higher percentages of protein than the C hybrids (54.2 vs. 55.7% and 15.1% vs. 12.0%, respectively). Nitrogen application did not affect seed oil concentration (HO: 0N = 54.4% vs. 120 kg N/ha = 54.0%; C: 0N = 55.2% vs. 120 kg N/ha = 55.7%). However,

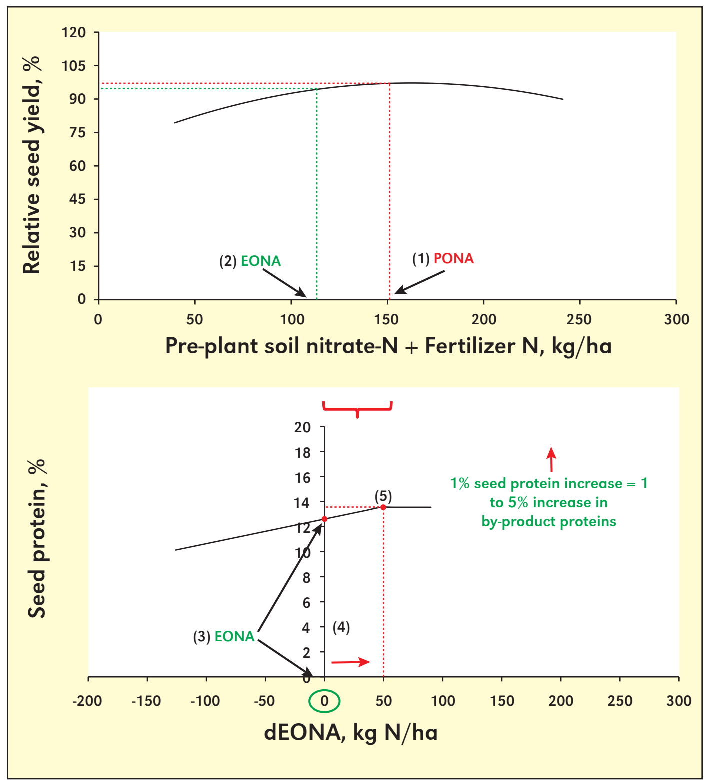

Figure 4. Relationships between relative seed yield (RSY) and N availability at planting (top), and seed protein and the differential economic optimum N availability (dEONA) for conventional hybrids. Production optimum N availability (PONA) [1] indicates the production optimum N availability, and EONA [2] the economic optimum N availability, [3] shows the seed protein level at dEONA, [4] is the increase in N rate above EONA to maximize seed protein, [5] is the optimum seed protein level.

seed protein concentration increased, on average, by 1.9% and 2.5% with the highest N rate for HO and C hybrids, respectively. Therefore, the protein/oil ratio increased linearly with N application. In summary, N application did not affect seed oil concentration, but would increase seed and by-products protein concentration.

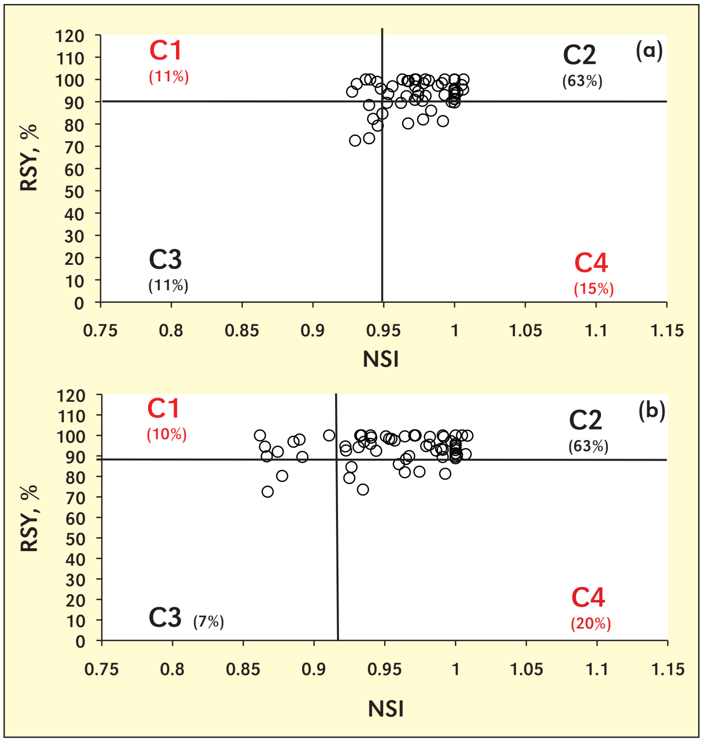

Figure 5. Relative seed yield (RSY) as a function of NSI at sunflower stages V_6 (a) and V_{12} (b) (Schneiter and Miller, 1981). The vertical lines indicate the critical threshold for N sufficiency index (NSI), while the horizontal lines indicate 90% of RSY. Quadrants C1 and C4 show incorrect diagnosis, and quadrants C2 and C3 show correct diagnosis. Data between parentheses represent the percentage of cases in each quadrant over the total number of cases.

Diagnosing N Needs

Nitrogen availability at planting (NA = PPSNT+FN) explained 46% of the variation in relative seed yields (RSY) (**Figure 3**). According to this model, a maximum seed yield of 4,000 kg/ha would be reached with NA of 150 kg N/ha, 37.5 kg of available N per t seed. No relationship was found between RSY and 6-leaf SNT, probably because of excessive water (120 mm) before soil sampling.

Considering a price ratio of 4.5 kg sunflower seed per kg N (4.5:1 ratio), the EONA averaged 110 kg N/ha for both genotypes (i.e., 40 kg N/ha less than the PONA). However, seed protein concentration increased with higher NA than the EONA. This situation would create potential bonuses of protein pellets and flour in the international market. In this study, it was determined that the application of 48 and 90 kg N/ha above the EONA (differential EONA, dEONA) in genotypes C and HO would maximize the concentration of protein in seed, reaching values of 13.6 and 16.5%, respectively. **Figure 4** shows an example for C genotypes relating the diagnosis method based on NA with the RSY; and dEONA to maximize the percentage of protein. The application of about 48 kg N/ha above the EONA (dEONA = 0) allowed seed protein to increase by nearly 1%, and by-product proteins by 5%.

The NSI was affected by N application at both stages, V6 and V12, while fertilization only affected NDVIr at V12. Moreover, significant relationships between NSI and NA were observed (r^2 of 0.39 and 0.42 at V6 and V12, respectively). Relationships of NA and NDVIr were also significant, but to a lesser magnitude (r^2 = 0.13 and 0.17, for V6 and V12, respectively). This would indicate that NDVIr did not properly relate to N availability. Moreover, using the quadrant methodology (Cate and Nelson, 1965), the NSI correctly diagnosed 74% and 70% of the points (quadrants C2 + C3) for V6 and V12, respectively (critical threshold: 0.95 and 0.92, respectively) (**Figure 5a** and **5b**). Although both sensors contributed to the diagnosis of N deficiency in sunflower, SPAD showed a better performance compared to GreenSeeker.

Summary

Nitrogen application in sunflower would increase seed yield and seed protein concentration without affecting seed oil concentration. Moreover, NA (PPSNT + FN) allowed the determination of optimum N availability for seed yield and maximized seed protein concentration, which would increase the quality of the flour and pellets. Meanwhile, the SPAD measurements have proved to be a tool that could complement soil N diagnosis and requires further investigation for practical use. BC

Ms. N. Diovisalvi is with Fertilab Soil Testing Laboratory, ndiovisalvi@laboratoriofertilab.com.ar; Dr. N. Reussi Calvo is with Fertilab, Unidad Integrada INTA-FCA Balcarce, and CONICET; Mr. Divito and Mr. Echeverria are with Unidad Integrada INTA-FCA Balcarce; Mrs. Izquierdo is with Unidad Integrada INTA-FCA Balcarce and CONICET; and Dr. Garcia is Director, IPNI Latin America Southern Cone Program, Acassuso, Buenos Aires, Argentina.

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Phosphogypsum Use to Reduce Subsoil Acidity: The Brazilian Experience

By Luís Prochnow, Eduardo Caires, and Camila Rodrigues

Phosphogypsum can help to improve subsoil conditions in certain circumstances, which favors plant root development.

Better root growth in acidic soils translates into increased water and nutrient uptake by crops leading to higher yields, profitability, and sustainability

It is estimated that at least 50% of agricultural soils in the world are acidic (i.e., low soil pH), a condition that severely affects the development and yield of most commercial crops. The most common effects of soil acidity are: toxicity to Al^{3+}, low availability of plant nutrients, poor soil physical and microbiological conditions (including symbiotic N fixation in legumes), and low effectiveness of certain herbicides.

The improvement of soil and subsoil acidity is a key management practice for high yields, profitability, and sustainability. Research shows positive response to acidity-reducing inputs for a wide range of crops, with yield gains as high as 500%. A major component of soil acidity management is the application of lime but other practices, mainly phosphogypsum (PG) use and cultivar selection, are beneficial. Examples provided below highlight the Brazilian experience, but this information is relevant to many regions affected by subsoil acidity.

Phosphogypsum Properties

Phosphogypsum ($CaSO_4{\cdot}2H_2O$) is a by-product of phosphoric acid production and PG's most common agricultural uses are as a direct source of Ca or S to plants, an additive during manure composting, for improvement of saline-sodic soils, and for reduction of subsoil acidity. Generally, the main constraints for any particular PG source are its chemical and physical properties, as well as any prohibitive cost of transportation. Pre-treating PG to improve its quality (i.e., creating a product with lower moisture and a more uniform particle-size) can improve PG product acceptability. Legislative limits to radionuclide concentrations in soil amendments can limit or even prohibit the use of PG for many regions of the world, but this issue is under continuous review. Sedimentary phosphate rock sources have higher radioelement concentrations compared to phosphate rock from igneous sources.

Chemically, PG is a neutral salt with much higher solubility than lime and with no direct effect on soil pH. While aglime (Ca and/or $MgCO_3$) can increase soil pH, due to the CO_3 (carbonate) that leads to the formation of a weak acid (H_2CO_3), gypsum or PG can not since its anion SO_4^{2-} (sulfate) leads to the formation of a strong acid (H_2SO_4).

Aglime vs. Phosphogypsum

Research shows that PG reduces subsoil acidity leading to positive influences on plant root development. This is especially important in rainfed cropping systems, where root absorption of water and nutrients at deeper soil layers may be limited under water stress, thereby affecting plant growth. Plant roots do not grow well with elevated concentrations of Al^{3+} or in Ca-deficient zones in the soil. Plant root tips need Ca for adequate elongation, but plant roots developing in deeper soil layers with limited amounts of Ca are unable to take advantage of Ca absorbed by plants in the upper soil layers because Ca^{2+} does not move through the plant phloem. Because gypsum has higher water solubility than lime, it can dissolve and leach through the soil profile adding significant amounts of Ca and SO_4^{2-} at depths where lime would not reach. The increase in SO_4^{2-} concentration in deeper soil layers will favor its combination with Al to form $AlSO_4^{+}$, which diminishes the activity (and toxicity) of Al^{3+}. At the same time, the plant availability of Ca is increased, which favors the elongation of plant roots in the acidic subsoil. **Figure 1** is an example of the effect of Ca

Abbreviations and notes: N = nitrogen; K = potassium; S = sulfur; Ca = calcium; Mg = magnesium; Al = aluminum.

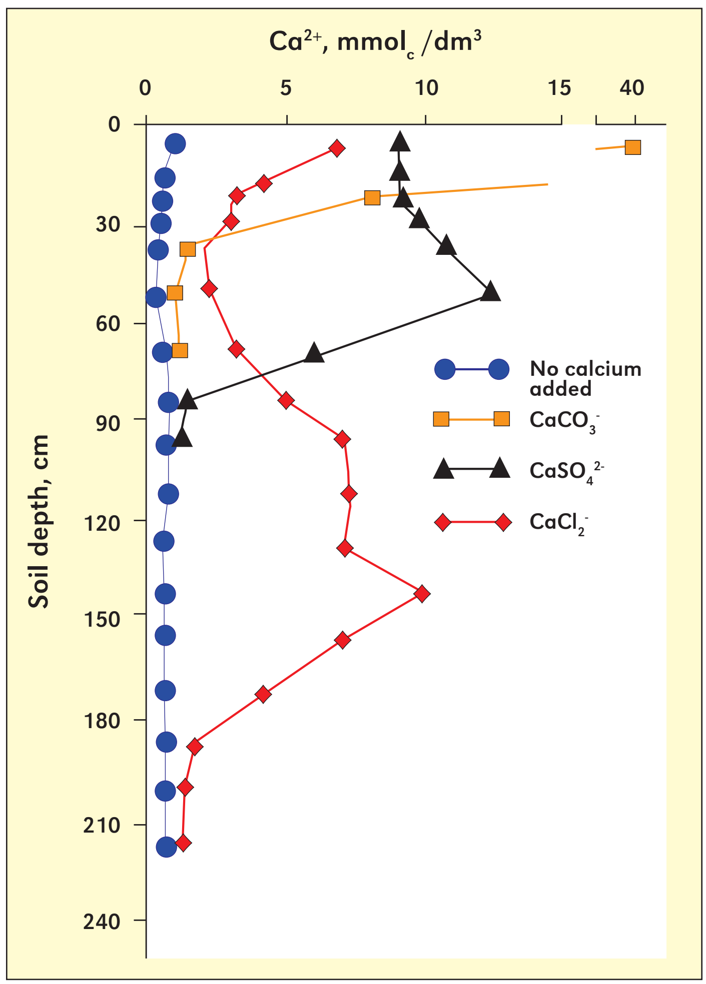
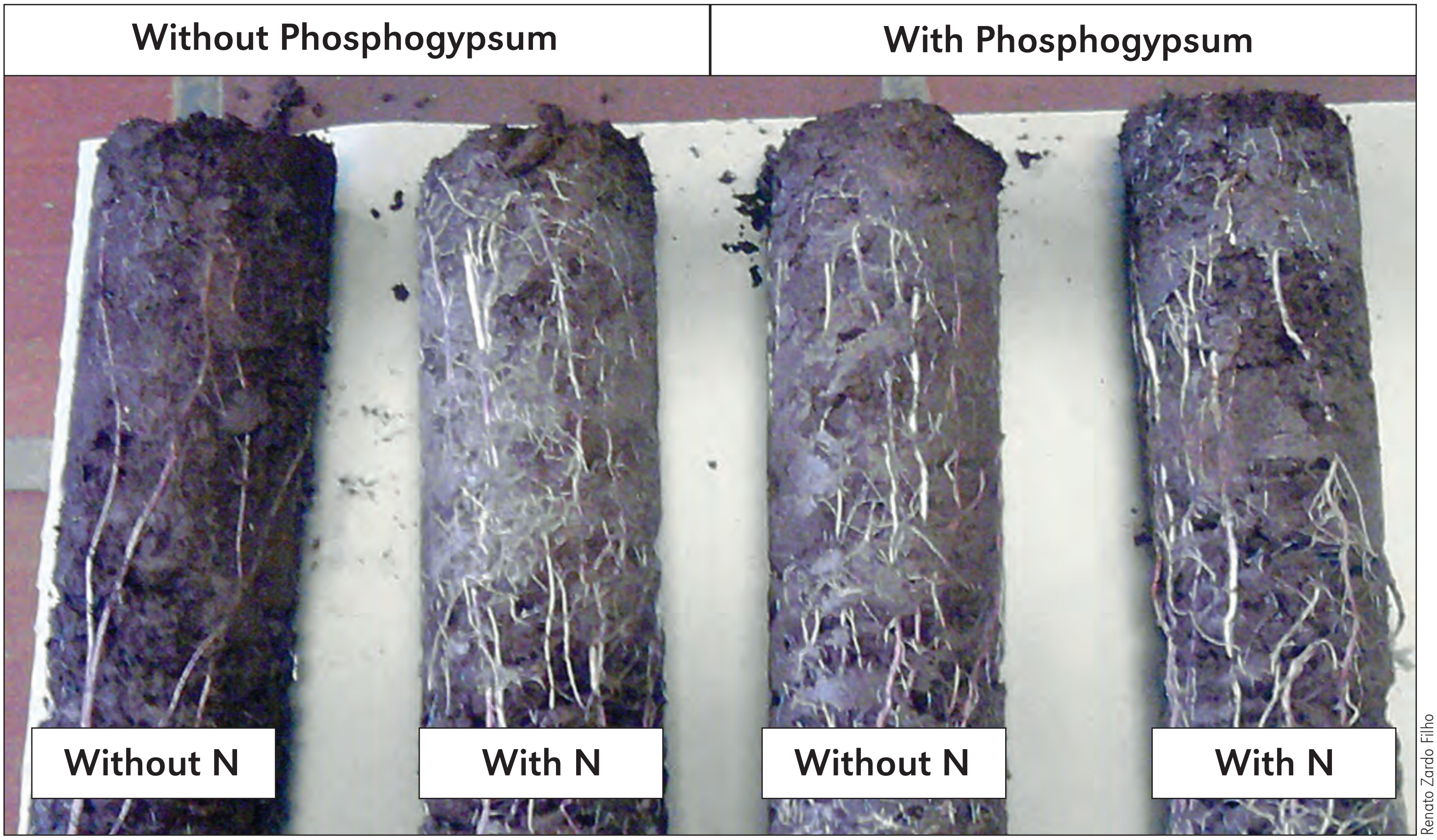


Figure 1. Distribution of Ca in soil layers of a Brazilian oxisol for different Ca sources after addition of 1,200 mm of water (Sousa and Ritchey, 1986).



Corn root growth at 40 days after emergence to a 50 cm depth in undisturbed soil columns as affected by phosphogypsum and nitrogen (N) applications.

leaching through the soil profile when the cation is combined with different anions (CO_3^-, SO_4^{2-}, or Cl^-). It is clear that for the sulfate source, Ca^{2+} moves in the soil profile to a position that is available to plant roots, while the CO_3^- source provides too little movement of Ca^{2+}, and the Cl^- source provides it in excess.

Thus aglime should be used respecting the 4R approach (right source, rate, time, and place) to neutralize soil acidity within the top 20 to 30 cm of the soil surface. Gypsum or PG, also considering the 4R approach, should be used in certain soil conditions to reduce subsoil acidity. A PG product has little effect within the surface soil layer, which is critical information for farmers. When PG was first introduced in Brazil during the mid 1980s, many farmers applied it with the impression that it would have the same effect as lime. In fact, high rates of PG created a cation imbalance and limited plant growth.

Phosphogypsum Research

A classical field trial by Ritchey et al. (1980) was key in suggesting that PG could be used to reduce subsoil acidity. The authors were in fact comparing single and triple superphosphate (SSP, TSP) as sources of P in maize with no initial goal to test PG. During one season with very little rain the researchers noticed that plants under high rates of SSP were performing much better than those under low rates of SSP or any rate of TSP. Their curiosity lead to an analysis of the different soil layers and the results clearly showed more roots and higher contents of Ca^{2+}, and lower Al^{3+}, at greater soil depths in plots where high rates of SSP were applied (**Table 1**). Pavan and Bingham (1982) also showed that $CaSO_4$ could decrease Al^{3+} toxicity to plants due to the formation of a soluble $AlSO_4^+$ complex.

Table 1. Effect of single (SSP) and triple superphosphate (TSP) on pH, Ca + Mg, Al, Al saturation, presence of corn roots, and water content in soil layers of a Brazilian oxisol (Ritchey et al., 1980).

Soil depth, cm	pH		Ca + Mg, $mmol_c/dm^3$		Al, $mmol_c/dm^3$		Al saturation, %		Roots, present or not		Water, ml/L	
	TSP	SSP	TSP	SSP	TSP	SSP	TSP	SSP	TSP	SSP	TSP	SSP
0-15	5.4	5.1	34	19	0.3	3.1	1	14	Yes	Yes	136	166
15-30	5.0	4.7	21	13	2.9	5.6	12	30	Yes	Yes	181	199
30-45	4.6	4.7	8	14	7.1	3.7	47	21	Yes	Yes	202	217
45-60	4.1	4.8	5	15	7.8	2.0	61	12	Yes	Yes	227	206
60-75	4.0	4.5	4	11	6.5	2.3	62	17	No	Yes	236	208
75-90	4.2	4.6	2	8	5.4	1.8	73	18	No	Yes	243	233
90-105	4.2	4.3	1	5	4.0	1.4	90	22	No	Yes	250	232
105-120	4.2	4.4	1	5	2.8	0.4	74	8	No	Yes	253	241

Table 2. Nitrogen uptake by corn above-ground tissues and the concentration of leached NO_3-N as affected by phosphogypsum and nitrogen applications to soil columns (Caires et al., 2016).

	Without N	With N
Phosphogypsum (PG)	Nitrogen uptake, mg/plant	
Without PG	66.1	91.9
With PG	112.5	159.6
Increase (%)	70	74
	Leached NO_3-N, mg/L	
Without PG	7.3	11.4
With PG	6.8	6.4
Decrease (%)	7	44

These results, with additional information from the literature, especially from South Africa, inspired many Brazilian studies to follow. In one of these experiments, the use of PG showed economic viability to maximize crop grain production under a long-term no-till system (Caires et al., 2011). More recently, Caires et al. (2016) found that improved subsoil acidity due to PG in a no-till corn system also increased N use efficiency (NUE), improved grain yield, and reduced environmental risks due to NO_3-N (nitrate) leaching. Since PG application potentially promotes root development in deeper soil layers, application may improve NUE by increasing N uptake, especially from NO_3-N that readily moves to the subsoil (**Table 2**).

Conclusion

Application of lime is no doubt the best alternative to alleviate topsoil acidity and provide conditions for adequate crop development. No other practice is as efficient and economical as soil liming. However, alternatives such as PG application might be of use under specific situations—namely managing detrimental effects of subsoil acidity. Better root growth at depth translates into more efficient water and nutrient use by plants. As with any product, PG should be applied according to the concepts of 4R Nutrient Stewardship that ensure a right source, rate, time, place combination in the field. BC

The abundance of research from Brazil has established good 4R management practices for the appropriate use of PG in soils. Such practices are summarized as:

Right Source: Phosphogypsum should be used in accordance with country regulations. Regulations especially related to radioelement concentration are under review in many parts of the world. In Brazil, because PG originates from igneous phosphate rock, radioelement concentrations are low and not considered problematic. PG should be uniform, dried, and analyzed for Ca and S concentrations. On average, PG is expected to have 20% Ca and 15% SO_4-S. Transportation is the main cost consideration for PG and it can restrict its use in certain areas. In Brazil, PG use is thought to be cost effective within 500 miles of its origin.

Right Rate: A right PG rate is fundamental in improving subsoil acidity. Lower than necessary rates may not achieve the desired effect. Applying too much PG can lead to undesired side effects that, for example, can carry Mg and sometimes K to deeper soil layers that plant roots can not reach. For Brazilian oxisols, PG should be applied according to the following formula:

PG = clay x 50, where PG = amount of PG (kg/ha), and clay = % clay content in the (20 to 40 or 40 to 60 cm) subsoil layers.

Right Time: Phosphogypsum should be applied after lime reaction so PG does not limit dissolution of the lime in the soil. Phosphogypsum should be applied before crop seeding in cereal crops. For perennial crops, PG can be applied before crop establishment or anytime during the crop's lifetime, when needed.

Right Place: The application of PG is only recommended when analysis of deeper soil layers (20 to 40 or 40 to 60 cm) shows exchangeable Ca^{2+} content < 5 $mmol_c/dm^3$, exchangeable Al^{3+} content > 5 $mmol_c/dm^3$, and/or Al^{3+} saturation > 20%. The product should be applied over the soil surface.

Dr. Prochnow is Director, IPNI Brazil Program, Piracicaba, São Paulo (E-mail: lprochnow@ipni.net); Dr. Caires is a Professor at the State University of Ponta Grossa, Ponta Grossa, Parana (E-mail: efcaires@uepg.br); Ms. Rodrigues is a student at the State University of São Paulo, Botucatu, São Paulo.

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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. BC

EARY BIRD REGISTRATION ENDS AUGUST 26, 2016. DON'T MISS OUT!

Understanding Potato Yield and Economic Responses to Fertilizer

By Shutian Li, Yu Duan, Zhanquan Chen, Tianwen Guo, and Youhong Li

Researchers established a network of field trials in northwest China designed to test the response of potato to N, P, and K fertilizer and the crop sensitivity to price fluctuations.

NPK fertilization responses are commonly significant and economic for this important production center.

In response to expanding consumer demand, China's potato production is by far the world's largest. China's production reached 88 million t in 2011 (China Agriculture Statistics Data, 2011), which is nearly four times the 23.3 M t produced in the U.S. and Canada (USDA, 2015). China's semi-arid northwest produces 34% of its total potato crop annually. For the northwest, potato remains both a primary economic and staple food crop.

Potato usually takes up much more N and K than P (Perrenoud, 1993; Fageria et al., 1997; Westermann, 2005). Inadequate N can lead to reduced growth and yield while excessive N leads to delayed maturity, reduced uptake efficiency, and can increase the potential for environmental issues associated with leaching or runoff (Kumar et al., 2007a). Although potato requires less P than N and K, P promotes the development of large tubers (Kumer et al., 2007b). These are well-known facts concerning potato crop nutrition, but in northwest China a lack of specific information on potato yield response to fertilizer application creates a general knowledge gap concerning the main nutrient limitations as well as best management practices for the crop. As part of the IPNI national cooperative research network, on-farm field trials were arranged in Inner Mongolia Autonomous Region (IMAR), and the northwestern provinces of Ningxia, Qinghai, and Gansu between 2002 and 2011 to address this knowledge gap.

Each trial tested a recommended (OPT) practice and a series of nutrient omission plots (i.e., OPT-N, OPT-P, OPT-K). Nutrient application within the OPT was recommended after soil testing according to the ASI procedure (Portch and Hunter, 2002). Descriptions of soil testing data and field trial information are summarized in **Table 1** and **Table 2**.

Table 1. Important soil properties (mean +/- standard deviation) prior to trial establishment.

Soil parameters	N trials	P trials	K trials
Soil texture	Sandy loam, loam	Sandy loam, loam	Sandy loam, loam
pH in water (1:2.5)	8.3 ± 0.3	8.2 ± 0.2	8.2 ± 0.2
Soil organic matter, g/kg	10.0 ± 5.0	9.0 ± 5.0	9.0 ± 5.2
Mineral N, mg/L	29 ± 22	27 ± 22	26 ± 21
Available P, mg/L	18 ± 9	18 ± 8	18 ± 8
Available K, mg/L	99 ± 36	100 ± 34	99 ± 33

Table 2. Summarized details of field trials conducted in northwest China.

Variable	IMAR	Qinghai	Gansu	Ningxia
Cultivar	Zihuabai	Xiazhai-65	Longshu-3	Qingshu-168
Planting date	May 5-20	Apr. 19-29	Mar. 30-Apr. 17	Apr. 22
Harvest date	Sep. 12-15	Sep. 15	Sep. 22	Oct. 7
Plant density/ha	40,000-50,000	40,000-50,000	40,000-50,000	40,000-50,000
	------------ Nutrient used in OPT, kg/ha ------------			
N	45-300	136-214	75-225	150
P_2O_5	30-250	60-172	60-150	150-225
K_2O	30-225	84-225	60-150	150-300

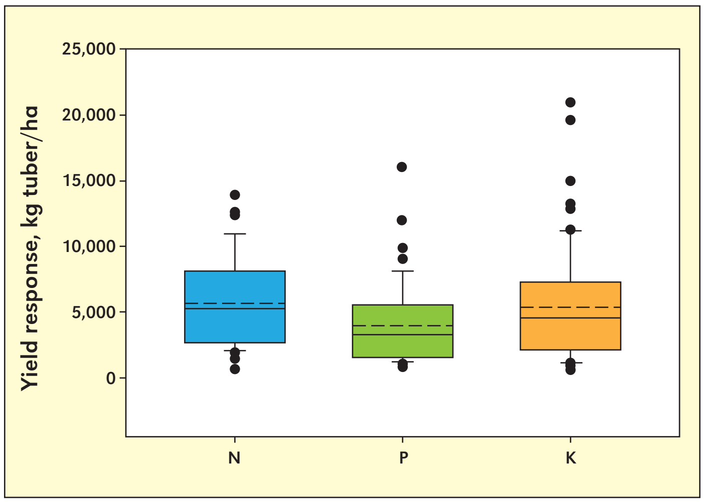

Figure 1. Variability of yield response among 44 data points for N, 49 data points for P, and 80 data points for K collected from studies across northwest China. The boundary of the box closest to zero indicates the 25th percentile, a black line within the box marks the median, a short dash line marks the mean, and the boundary of the box farthest from zero indicates the 75th percentile. Error bars above and below the box indicate the 90th and 10th percentiles and outliers are black dots.

Yield Responses

The trials found large tuber yield responses to fertilizer nutrients, but responses varied significantly across sites and years (**Figure 1**). In summary, 42 of 44 trials had significant (p<0.05) yield increases for N, 37 of 49 trials for P, and 65 of 80 trials for K. Average yield responses to N, P, and K were 5,660 kg/ha (25%), 3,970 kg/ha (18%), 5,340 kg/ha (18%), respectively. Thus, N was the most yield limiting followed by K and P.

Economic Analysis for Fertilizer Application

Application of N, P, and K fertilizer resulted in average

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium. 1US$ = 6.5 Chinese Yuan.

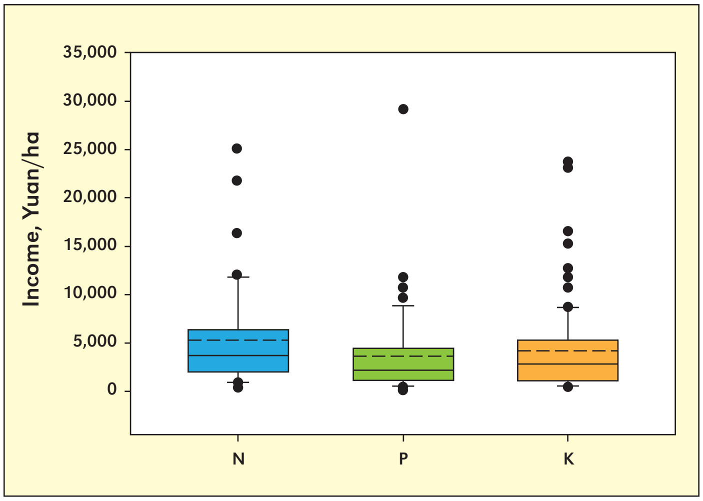

Figure 2. Variability of income by fertilizer application among 44 data points for N, 49 data points for P, and 80 data points for K collected from studies across northwest China. The boundary of the box closest to zero indicates the 25th percentile, a black line within the box marks the median, a short dash line marks the mean, and the boundary of the box farthest from zero indicates the 75th percentile. Error bars above and below the box indicate the 90th and 10th percentiles and outliers are black dots.

incomes of 5,220, 3,680, and 4,140 Yuan/ha, showing more benefit from N and K than P fertilizer (**Figure 2**).

The value-to-cost ratio (VCR = benefit from fertilization/fertilizer cost) represents the economic return of a unit invested, in this case, N, P, or K fertilizer. The VCR for N, P, and K ranged between 2.0 to 34.4, 1.1 to 59.3, and 1.6 to 39.6 with the respective averages being 9.3, 12.7, and 8.8 (**Figure 3**). The wide variability in VCR is a reflection of the range of yield responses obtained; however, it is apparent that any investment in fertilizer, regardless of nutrient, contributed to the profitability of potato production.

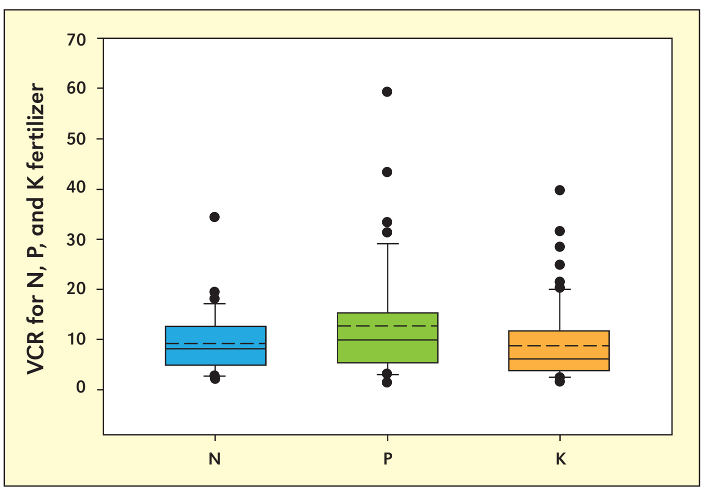

Figure 3. Variability of value-to-cost ratio (VCR) among 44 data points for N, 49 data points for P, and 80 data points for K collected from studies across northwest China. The boundary of the box closest to zero indicates the 25th percentile, a black line within the box marks the median, a short dash line marks the mean, and the boundary of the box farthest from zero indicates the 75th percentile. Error bars above and below the box indicate the 90th and 10th percentiles and outliers are black dots.

Table 3. Critical yield response (VCR=1) at various scenarios of fertilizer rate and price for profitable income.

		---------------- kg N/ha ---------------				
		100	150	200	250	300
--- Yuan/kg N ---		----- Critical yield response, kg/ha -----				
2011 price	4.80	716	1,075	1,433	1,791	2,149
25% increase	6.00	896	1,343	1,791	2,239	2,687
50% increase	7.20	1,075	1,612	2,149	2,687	3,224
		------------- kg P_2O_5/ha -------------				
		45	60	90	120	150
--- Yuan/kg P_2O_5 ---		----- Critical yield response, kg/ha -----				
2011 price	4.52	304	405	607	810	1,012
25% increase	5.65	379	506	759	1,012	1,265
50% increase	6.78	455	607	911	1,214	1,518
		------------- kg K_2O/ha -------------				
		90	120	150	180	225
--- Yuan/kg K_2O ---		----- Critical yield response, kg/ha -----				
2011 price	6.67	896	1,195	1,493	1,792	2,240
25% increase	8.34	1,120	1,494	1,867	2,241	2,801
50% increase	10.01	1,345	1,793	2,241	2,689	3,362

The potato tuber price was 0.67 Yuan/kg, the lowest between 2002-2011.

In order to evaluate the effect of price fluctuation on VCR, multiple fertilizer price scenarios were tested to represent current and future prices (i.e., low, medium, high, high x 1.25, and high x 1.5). This economic analysis was evaluated within three yield response and fertilizer rate scenarios (i.e., low, medium, and high) represented by the 25, 50, and 75 percentiles (**Figure 1**).

Under a less responsive scenario, (2,700, 1,500, and 2,100 kg/ha) and low application rate (120-62-90 kg N-P_2O_5-K_2O/ha) VCR was 1.6, 1.7, and 1.1, respectively, at the highest fertilizer price/lowest potato tuber price simulation. Given the same prices, at the high response scenario, (8,000, 5,410, and 6,890 kg/ha) and high rate (210-115-150 kg N-P_2O_5-K_2O/ha) VCR was 2.6, 3.4, and 2.1, respectively. **Figure 4** provides the results of the mid-response/mid-rate scenario. The data demonstrated a >75% probability of profitability from N, P, or K fertilization within northwest China potato fields, and that profits will rise with increased yield response.

The critical yield response (VCR=1) where fertilizer investment cost was equal to return was also calculated using different scenarios of fertilizer rate and price, based on the lowest tuber price between 2002 to 2011 (**Table 3**). These critical yield responses to fertilizer further demonstrate that more response to K, compared to P or N, will be expected for profitable income. If fertilizer price increased 50% above the low of 2011, use of the high fertilization rate (300-150-225 kg N-P_2O_5-K_2O/ha) generated respective critical yield responses for N, P, and K of 3,224, 1,518, and 3,362 kg/ha. This suggested that 73%, 76%, and 60% of trials would be profitable with application of N, P, and K, respectively. If the calculation were based on low price of 2011 and the same high fertilization, 89%, 94%, and 74% of trials could be profitable.

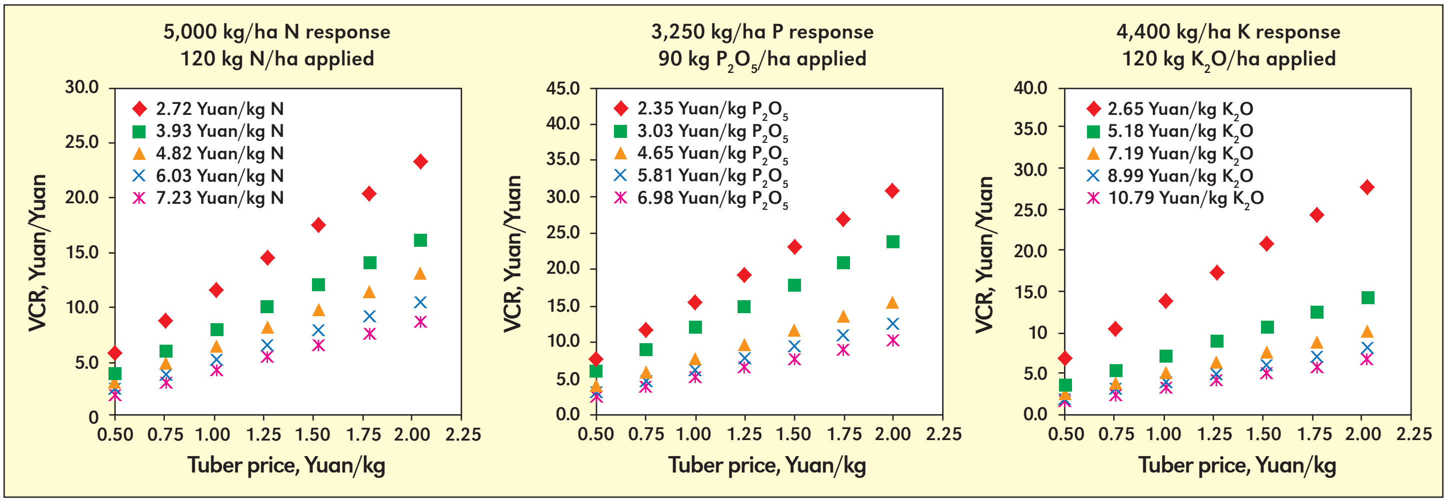

Figure 4. Expected value-to-cost ratio (VCR) changes with fertilizer and tuber price fluctuations under the middle yield response/fertilization scenario.

Conclusions

Nitrogen was the main yield-limiting nutrient for potato production in northwest China followed by K, and then P. Application of N, P, or K fertilizer can be profitable in the region in the face of fluctuating crop and fertilizer prices. A host of factors ranging from marketing to food policy can have an effect on fertilizer and tuber prices. Increased demand for potato will require higher yields and careful fertilization. A 4R Nutrient Stewardship approach integrated with other practices like water management will be required to increase yield response and profit. Future work should focus on 4R nutrient management integrated with other agronomic practices to further improve yield responses and profitability. BC

Comparison of potato growth between the NPK optimum (OPT) treatment and the K omission (OPT-K) treatment in Gansu province.

Dr. Li is Deputy Director for IPNI Northwest China Program (E-mail:sli@ipni.net); Mr. Duan is a Professor, Institute of Plant Nutrition and Analysis of Inner Mongilia Academy of Agricultural Sciences; Mr. Chen is a Professor, Soil and Fertilizer Institute, Qinghai Academy of Agriculture and Forestry; Mr. Guo is a Professor, Dryland Agriculture Institute, Gansu Academy of Agricultural Sciences; Mr. Li is a Professor, Soil and Fertilizer Institute, Ningxia Academy of Agriculture and Forestry Sciences.

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Plant Nutrients in Palm Oil

By Christopher R. Donough, Angger Cahyo, Ruli Wandri, Myles Fisher, and Thomas Oberthür

An apparent knowledge gap concerning the amount of plant nutrients in palm oil motivated a study to determine plant nutrient content in palm oil and assess the impact of fertilizer management on such content.

Export of plant nutrients was low in palm oil extracted by industrial mills; part of the nutrients likely remain in post-milling residues.

Selected nutrients in palm oil were affected by fertilizer application rate, but not timing or frequency.

Research documented nutrient removal from harvested oil palm fresh fruit bunches (FFB). Reports from Southeast Asia and Africa show that each t of FFB contains 3.0 to 5.0 kg N, 0.3 to 0.7 kg P, 3.5 to 5.3 kg K, and 0.5 to 0.9 kg Mg (Tinker and Smilde, 1963; Ng and Thamboo, 1967; Tarmizi and Mohd Tayeb, 2006; Prabowo et al., 2006; Donough et al., 2014). There are reports of nutrient contents in post-milling residues after processing and extraction of palm oil and palm kernels from the FFB. These are for the empty fruit bunches (EFB) and the palm oil mill effluent (POME). The nutrients in the post-milling residue do not fully reconcile with pre-milling values (Prabowo et al., 2006). This suggests that the palm oil and palm kernel may contain some of them, or there could be unaccounted loss in the milling process. In a review of the fate of plant nutrients in palm oil production, Corley (2009) wrote that, "palm oil contains no N or K, and only about 20 g of P per tonne." Beyond this, there is virtually no information for contents of plant nutrients in palm oil.

The International Plant Nutrition Institute (IPNI), received an inquiry about the S content in palm oil in 2014. At the time, the Southeast Asia Program (SEAP) of IPNI sampled FFB in a project in Kalimantan for bunch analysis (BA, procedure shown in **Figure 1**, from Oberthür et al., 2012) to estimate yield of crude palm oil (CPO) and palm kernel. For this paper, the extracted samples of palm oil were analyzed. First, to determine the content of plant nutrients in CPO from BA (referred to as 'BA CPO'). This will show the portion of exported nutrients in FFB that the oil contains. Second, since the Kalimantan project compared different fertilizer managements, the results should also indicate if these had any influence on nutrient contents in the BA CPO. Third, to compare BA CPO with CPO from an industrial mill to make a balance sheet to identify where nutrient losses occur in the palm oil milling process.

The Kalimantan Project

The Kalimantan project validated the hypothesis that applying fertilizer more frequently, in line with 4R Nutrient Stewardship, will improve nutrient use efficiency (NUE) on sandy soils, and increase yields. In our project 'nutrient best management practice' (NBMP), the application of fertilizer mixtures supplying N, P, K, Mg, S, and B four times yearly, was compared to standard estate practice (SEP) where single nutrient fertilizers are applied once or twice annually (**Table 1**). The project included a reduced fertilizer rate treatment with 80% of the full rate. There were four treatments in a factorial design of two application frequencies (NBMP and SEP) and two application rates (full and reduced). There were three replicates: full-sized blocks, each 25 ha. Within each block, we embedded two plots each of 36 palms (of which the central 16 palms were recorded). One was fertilized in the same way as the rest of the block, the other left unfertilized.

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Ca = calcium; Mg = magnesium; Fe = iron; Zn = zinc; Cu = copper. IPNI Project SEAP-05

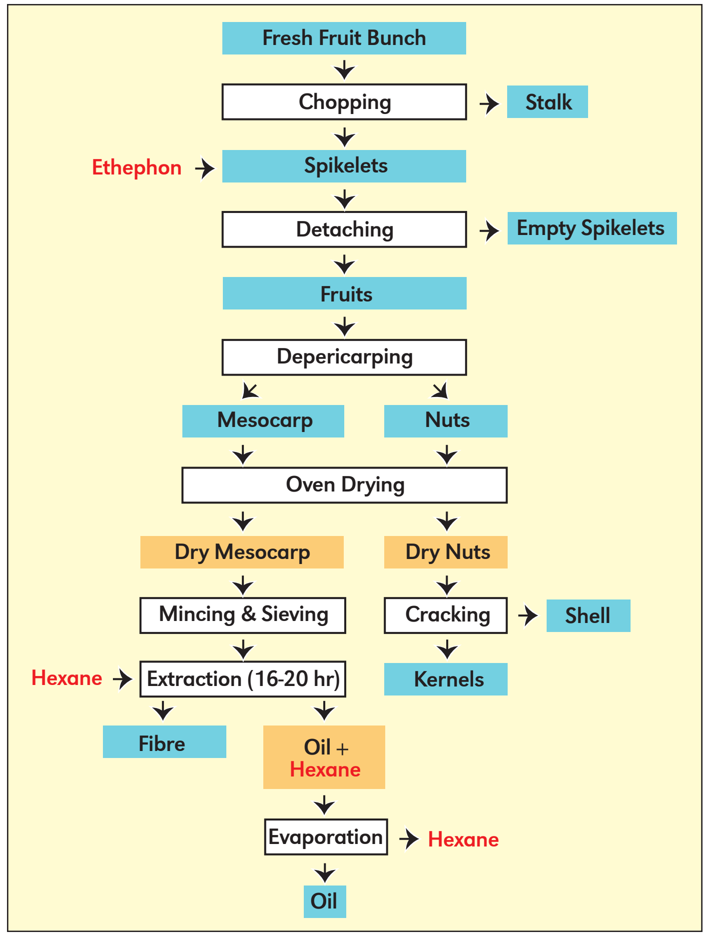

Figure 1. Bunch analysis procedure (Oberthür et al., 2012) implemented by IPNI Southeast Asia Program in Kalimantan, Indonesia.

Bunch Analysis versus Palm Oil Mill Processing

The BA CPO is obtained directly from individual FFBs (**Figure 1**), whereas the palm oil mill CPO is extracted from large batches of FFB (**Figure 2**). In the BA process, bunches are processed 'fresh', whereas the FFB in the mill is sterilized (cooked) using steam under pressure. BA bunches are chopped to separate the stalk from fruit-bearing spikelets, which are then sprayed with ethrel® (active ingredient is ethephon or 2-chloroethylphosphonic acid, $C_2H_6ClO_3P$, 21% P) to accelerate fruit abscission, and the fruits are separated from the

Table 1. Nutrient Management Practices in IPNI SEAP Kalimantan Project.

Treatment		NBMP[1]				SEP[2]		
Nutrient sources[3]	Urea Gr	Ammophos	Kornkali+B	Urea Pr	TSP	MOP	Kieserite	Borate
N-P-K-Mg-S-B contents	46-0-0-0-0-0	16-9-0-0-12-0	0-0-33-4-4-0.8	46-0-0-0-0-0	0-46-0-0-2-0	0-0-50-0-0-0	0-0-0-16-22-0	0-0-0-0-0-15
Annual frequency of application	4	4	4	2	1	2	1	1
Method of application	Mixed and applied manually			Each type individually applied manually				
Placement	Broadcast outside palm circles onto heaps of pruned fronds			Urea and borate applied onto soil surface inside palm circles; other fertilizers broadcast outside palm circles onto heaps of pruned fronds				
	Approximate[4] annual application rate, kg/ha - Full[5] rates shown							
Nitrogen, N		150		150				
Phosphorus, P		13			12			
Potassium, K		230				230		
Magnesium, Mg		25					26	
Sulfur, S		28			<1		34	
Boron, B		2						1

[1]Nutrient Best Management Practice; [2]Standard Estate Practice; [3]Urea Gr = granular urea, Urea Pr = prilled urea, TSP = triple superphosphate, MOP = muriate of potash or KCl; [4]Values vary slightly (less than +/- 5%) year-to-year; [5]Full rate based on annual FFB yield target = 21 t/ha, calculated for NPKMg only, S rate varies with type of fertilizers used; Reduced rate is approx. 80% of Full rate.

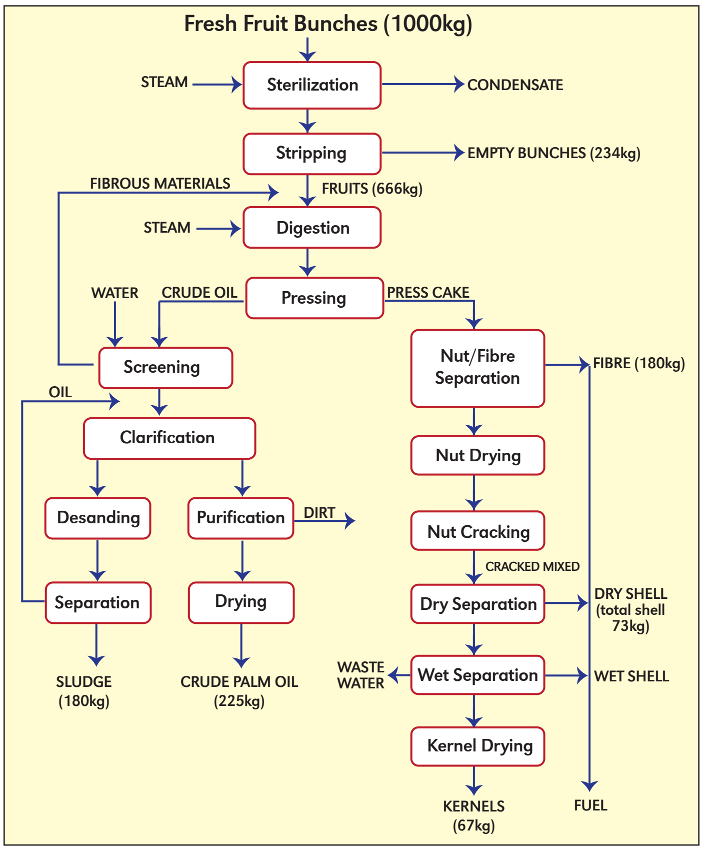

Figure 2. Typical milling process in a palm oil mill receiving fresh fruit bunches (FFB, top of figure) and extracting crude palm oil (CPO, left middle) and palm kernels (PK, right middle). From Siew (2011). Numbers shown for various components are from original author and do not add up.

spikelets manually. Each BA sample of 4 to 6 kg is sprayed with 250 ml of a 0.05% v/v solution so the concentration of P applied in ethephon per sample is 4 to 6 mg/kg. A sample will contain (approximately) the following components (expressed as % dry matter): spikelets (13%) and fruits, which consist of mesocarp (69%; containing oil that approximates 75 to 80% of the dry mesocarp), kernel (10%) and shell (8%). Distribution of the P from ethephon between the sample components is

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Oil palm mill receiving fresh fruit bunches for processing, Kalimantan, Indonesia.

not known, but not likely all of the 4 to 6 mg/kg added P will be in the extracted oil. In the palm oil mill, the cooked FFB is fed into a rotating drum thresher that strips fruits from the bunches (**Figure 2**).

In the BA process, the fruits are then manually separated into the mesocarp (that contains the CPO) and the seed nuts (that contain the palm kernels). The BA CPO is extracted from a sample of the (oven-dried and sieved) mesocarp using a soxhlet extractor with hexane (C_6H_{14}) as the solvent. In the palm oil mill, after cooking the fruits are fed into a rotating drum stripper and then into a digester where further heating with steam loosens the mesocarp from the nuts. Stirring arms in the digester help the process. The fruit 'digest' is then fed into a screw press where oil is pressed from the mixture of water, mesocarp fibres and nuts. The oil from the press ('crude oil' in **Figure 2**), is the 'initial crush' CPO, which is still mixed with solids from the 'digest'. The 'initial crush' CPO is screened to remove the larger non-oil particles, and then goes to a

Table 2. Nutrient contents in crude palm oil (CPO) from the mill and bunch analysis (BA), in g per tonne.

Nutrient	N	P	K	Mg	Ca	S	Fe	Zn	Cu
Mill CPO[1]	44	18	<10	3	9	11	3	<0.5	<0.5
BA CPO[2]	93	145	20	58	42	37	55	3.0	0.5

[1] Samples from palm oil mill (physical extraction by mechanical presses), taken from production oil tank after clarifying, cleaning and drying. Mean values of 3 samples.

[2] Samples from bunch analysis process (solvent extraction); mean values of 12 composite samples.

clarification tank where much of the remaining non-oil solids settle. The cleaner CPO is skimmed off the top and passes through a centrifuge to remove remaining solids, followed by drying under vacuum. The cleaned crude palm oil passes to a production tank as 'Mill CPO', which then goes on to palm oil refineries. Samples of BA CPO and Mill CPO were obtained for analysis and comparison.

Nutrients in Mill Crude Palm Oil and Bunch Analysis Crude Palm Oil

Samples from the palm oil mill production tank are representative of CPO sold to refineries. The analyses show that there are only very small amounts of plant nutrients exported with the Mill CPO (**Table 2**). The BA CPO values were many times higher than the mill CPO values for all nutrients except Cu (**Table 2**). The difference is likely attributable to differences in the oil extraction methods at the mill (mechanical pressing) and in BA (solvent extraction). An important difference is that in the palm oil mill, FFBs are pressure cooked prior to pressing, so that nutrients may be lost dissolved in the sterilizer condensate (**Figure 2**). In BA, FFBs were not pre-treated.

Further loss of nutrients may occur after pressing in the palm oil mill when the oil is clarified and cleaned to remove dirt and impurities, and dried. Indeed, the nutrients contained in initial crush CPO from the mill were even higher than the BA CPO (**Table 3**). This is likely because the BA process used clean samples of fruit mesocarp and the leachate in soxhlet process contains only solutes. In contrast, the CPO after crushing in the palm oil mill contains much solid materials from the fruit digest.

Influence of Fertilizer Management

Reducing the fertilizer applied to 80% of the full rate affected N and Ca in BA CPO, which increased (**Table 4**). BA CPO from unfertilized plots showed significantly lower contents of P, K, and Mg compared to plots that received the same fertilizers as the blocks (**Table 5**). This suggests that the additional P, K, and Mg in the CPO came from added fertilizers. Other nutrients in the fertilizers did not affect contents of the oil.

The results for P could be slightly increased by 4 to 5% by P added via the ethephon treatment, which added an estimated 4 to 6 g/t to the BA samples.

Removal Rate from Plantations

Contents of N, P, K, and Mg in FFB from the Kalimantan project had been reported earlier

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A sample for fresh fruit bunch analysis (main image). Fruit mesocarp is separated from each seed nut (bottom left) and then oil is extracted from the mesocarp by solvent extraction (bottom right).

(Donough et al., 2014). Those results are reproduced in **Table 6**, with addition of results for Ca and S previously not reported. Each t of FFB removed approximately 3 kg N, 0.4 kg P, 3.8 kg K, 0.6 kg Mg, 0.5 kg Ca, and 0.3 kg S. Assuming a FFB yield of 25 t/ha, this translates to per ha removal of 75 kg N, 10 kg P, 95 kg K, 15 kg Mg, 12.5 kg Ca, and 7.5 kg S. The proportion of total N and K in FFB contained in the BA CPO is <1%, compared with almost 10% of P. In the case of S, about 3% is in the BA CPO. Nutrient removal (per ha) in the oil, assuming the same 25 t/ha FFB yield above, is just 0.6 kg N, 0.9 kg P, 0.1 kg K, 0.4 kg Mg, 0.3 kg Ca, and 0.2 kg S.

Table 3. Nutrient contents in crude palm oil (CPO) from different milling stages, g per tonne.

Nutrient	N	P	K	Mg	Ca	S	Fe	Zn	Cu
Mill CPO[1]	44	18	<10	3	9	11	3	<0.5	<0.5
Initial crush CPO[2]	853	81	1,103	286	342	144	52	2.0	1.1

[1] Samples from palm oil mill (physical extraction by mechanical presses), taken from production oil tank after clarifying, cleaning and drying. Mean values of 3 samples analysed by IMS.

[2] Samples from palm oil mill crude oil tank immediately after pressing, results are average values from determinations by two laboratories (SRC and A&L), except for the N result from SRC only.

Table 4. Effect of nutrient management on nutrient contents in bunch analysis crude palm oil, in g per tonne.

Nutrient	N	P	K	Mg	Ca	S	Fe	Zn	Cu
NBMP[1] blocks	102	145	20	56	40	34	52	2.5	<0.5
SEP[2] blocks	85	145	20	60	44	39	58	2.9	<0.5
Full-rate blocks	73	142	19	55	36	42	54	3.3	<0.5
Reduced-rate[3] blocks	113	148	21	61	48	32	56	2.6	<0.5

[1] Nutrient best fertilizer management = nutrients mixed and applied 4 times a year (i.e., high frequency for every nutrient).

[2] Standard estate practice = nutrients applied singly, 1 to 2 times a year.

[3] 80% of full rate.

Table 5. Nutrient contents in bunch analysis crude palm oil - with and without fertilizers, in g per tonne.

Nutrient	N	P	K	Mg	Ca	S	Fe	Zn	Cu
Fertilized[1] plots	79	142	22	61	45	33	55	2.6	0.5
Unfertilized[2] plots	77	128	17	50	45	35	57	2.6	0.5

[1] Embedded plot in each block receiving the same fertilizer treatment as rest of the block.
[2] Unfertilized plot in each block.

Table 6. Nutrient contents in fresh fruit bunches (FFB) and in bunch analysis crude palm oil (BA CPO), in kg per tonne.

Nutrient	N	P	K	Mg	Ca	S
Whole FFB[1]	3.07	0.38	3.84	0.62	0.51	0.28
Proportion in BA CPO[2]	0.02	0.04	0.01	0.01	0.01	0.01
Proportion in BA CPO in %	0.8	9.5	0.1	2.3	2.1	3.3

[1] Contents in whole bunches, including CPO still in mesocarp. Mean of all four treatments.
[2] Contents in the oil extracted from whole bunches (bunch analysis CPO) and assuming an oil content of 25% in FFB.

Conclusions

This work closes a significant gap in oil palm relevant nutrient management knowledge, by clarifying the nutrient content in CPO.

CPO obtained from the palm oil milling process contains few plant nutrients (**Table 2**), indicating that most of the nutrients in FFBs reaching the mills must remain somewhere in the mill system. Therefore, recycling nutrients from the mills back to plantations is an opportunity for better nutrient use efficiency in palm oil production. Decision models on alternative uses for post-milling residues (e.g., for power generation) must factor in the opportunity cost of such nutrient recycling, as prices of fertilizers and fuel fluctuate.

Nutrient content in BA CPO was higher than that in Mill CPO (**Table 1**), most likely due to the difference between extraction by mechanical pressing of whole bunches and leaching with a solvent. While useful for monitoring at the experimental or plantation level, costly solvent extraction is not used at the industry level.

Fertilizer management, in this case different frequency of application and rates, had no effect on most plant nutrients in the extracted CPO. The contents of N and Ca fell when the rate of applied fertilizer increased from 80% to 100%. Explanations are uncertain without further investigation.

Applying fertilizers compared with no fertilizer increased P, K, and Mg in the CPO, indicating that some of the applied nutrients ended up in the oil component of FFB.

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Mr. Donough is Senior Oil Palm Adviser to IPNI SEAP (E-mail: crdonough@gmail.com). Mr. Cahyo is Research Assistant and Mr. Wandri is Agronomy Research Manager at PT Sampoerna Agro Tbk. Dr. Fisher is a Consultant for IPNI SEAP, and Dr. Oberthür is Director, IPNI SEAP, Penang, Malaysia.

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Mrs. Phyllis Pates Honored at Great Plains Conference

The Great Plains Soil Fertility Conference (GPSFC)—held biennially in Denver—is an important industry-extension meeting for the U.S. Great Plains and Canadian Prairies. The GPSFC attendee's professional affiliations vary, and range from university researchers to industry agronomists to boots-on-the-ground consultants and other Certified Crop Advisers. Thus, a broad audience is served by the conference, and considerable planning and preparation are understandably required. The conference planning committee has the responsibility of program planning, but program planning is of little consequence without the coordination and oversight of an almost endless array of conference details such as hotel, meeting room, and banquet arrangements. For the past twenty years these critical behind the scenes responsibilities have been masterfully attended to by Phyllis Pates, Administrative Assistant at IPNI's Brookings, South Dakota office. In recognition for her years of loyal and dedicated service, Phyllis was honored during this year's conference awards ceremony.

Mrs. Phyllis Pates receives award of recognition for 20 years of respected service to the Great Plains Soil Fertility Conference.

For more details on the Great Plains Soil Fertility Conference contact IPNI or visit:
http://www.ipni.net/ipniweb/conference/gpsfc.nsf

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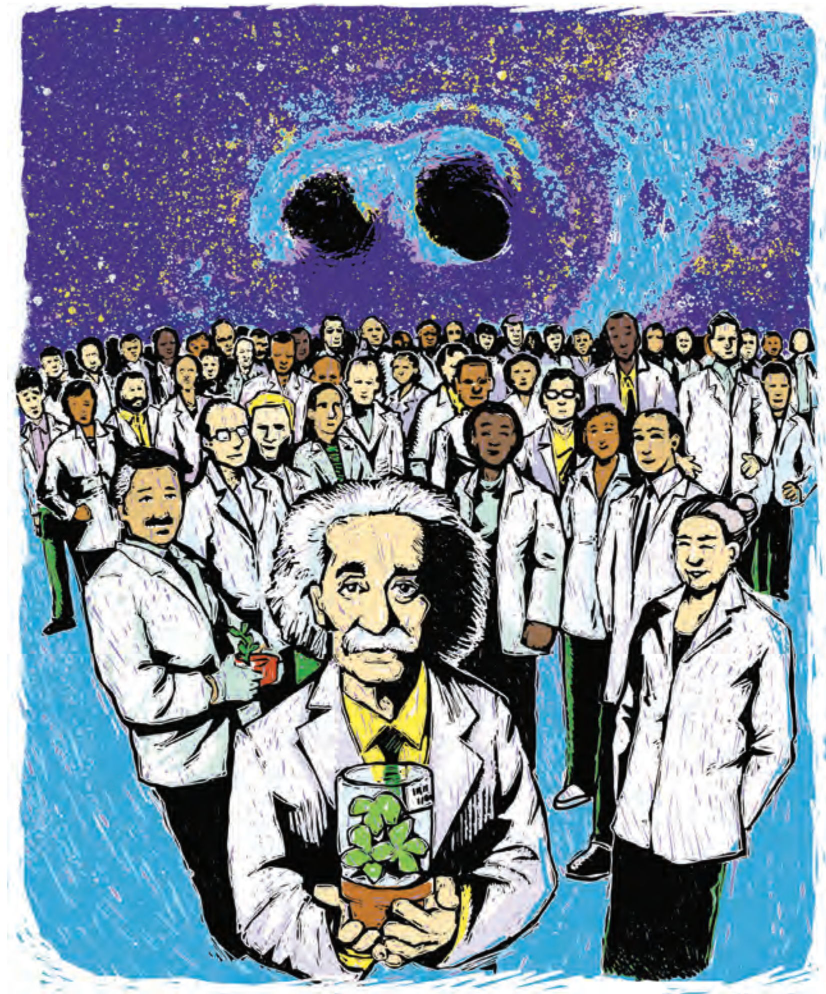
Plant Nutrition Lessons from Gravitational Waves

In 1916, based on the equations of general relativity, Albert Einstein predicted the existence of what he referred to as gravitational waves. These waves are distortions in "spacetime" resulting from huge shifts in mass somewhere in the universe. According to general relativity, it's the same phenomenon by which massive objects warp spacetime resulting in gravity. On February 12, 2016, a journal article was published that reported the physical measurement of gravitational waves. Computer models showed that the waves detected were caused by the merger of two black holes 1.3 billion light-years from Earth. On September 14, 2015, the resulting gravitational waves were measured at recently upgraded research facilities in Washington state and Louisiana, for the first time providing physical evidence that Einstein, 100 years ago, was right! This undoubtedly will be viewed as one of the major scientific advances of the century.



Now for the lessons on plant nutrition …

This absolutely amazing advance at first appears as a singular event. However, it was actually just one step (though very dramatic) in a century-long process of incremental advances by numerous scientists, each adding to the discoveries of those who went before. It's no different in the field of plant nutrition where our knowledge of products, practices and the systems they are a part of advance one study at a time. The contribution of each study is defined not only by the original data it contains, but also by the meta-data that connects the new study to previous ones and to those yet to come.

The second lesson resides in the authorship of the journal article itself. The article has 1,000 listed authors, occupying nearly three pages of the paper! Not only did this advance in the world of physics result from incremental advances across a century, it resulted from 1,000 researchers collaborating and sharing ideas and data. A key role of IPNI is to promote such collaboration through funding structures like Global Maize and by organizing regional conferences and workshops where personal relationships are built that open doors for collaborative efforts. It's the best way to "make waves" in advancing the science of nutrient stewardship.

Paul E. Fixen

IPNI Senior Vice President and Director of Research

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International Plant Nutrition Institute
3500 Parkway Lane, Suite 550
Peachtree Corners, Georgia 30092-2844
www.ipni.net