BETTER CROPS
WITH PLANT FOOD

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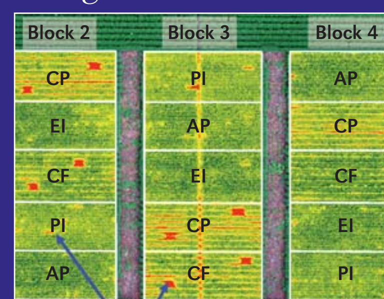
Impact of 4R Certification in the Lake Erie Watershed

Intensive Soybean Management



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Our cover: Phosphorus deficiency expressed on chickpea, Tamil Nadu, India.
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An Interview with 2016 IPNI Science Award Winner – Dr. Ismail Cakmak

The International Plant Nutrition Institute (IPNI) named Dr. Ismail Cakmak as the winner of the 2016 IPNI Science Award.

Since 2000, Dr. Cakmak has worked as a Professor of Plant Physiology at Sabanci University in Istanbul, Turkey. He received his B.Sc. from Cukurova University in 1980; his M.Sc. from Cukurova University in 1981; and his Ph.D. from Hohenheim University in 1988.

Cakmak is well known for his research on cereal crops and zinc nutrition. He directed a multi-institutional project, funded by the North Atlantic Treaty Organization (NATO), on the issue of zinc deficiency in Turkey (1993 to 1998). Following the identification of the zinc deficiency, zinc-containing NPK fertilizer use has increased from 0 to 600,000 t (annually) in Turkey.

The "HarvestZinc" international project was also developed by Cakmak under the HarvestPlus Program and was conducted in nine different countries (e.g., Asia, Africa, and South America). The focus was on using innovative application methods and micronutrient fertilizer combinations.

Q. Why did you launch the HarvestZinc project?

One third of the world populations suffers from micronutrient deficiencies, or hidden hunger. The problem particularly exists in the developing world where cereal consumption is very high. Our aim was to improve zinc and iodine status of the plant. There are two options, you can develop a breeding program, but that is a long-term process. The short-term solution is agronomic; we can apply zinc or iodine-containing fertilizer to the plant to enrich the edible parts of the plants quickly and it works very well.

Dr. Cakmak is also known for his work on the adverse effects of reactive oxygen species in plants that are under mineral nutrient deficiencies (e.g., zinc.). It was found that the adequate supply of mineral nutrients is critical for a plant's survival under stressful environmental conditions. He has published both research and review papers on this topic that have gained international attention.

Q. What aspect of your research has given you the most satisfaction?

In the past 30 years, I've focused mainly on zinc, a little bit on other nutrients, but mainly zinc. For the next 10 to 15 years, I will continue to focus on zinc. Again, focusing on a certain issue is very important because you can conduct more useful research, make more advancements, and generate more useful data when you have focused research.

Cakmak has authored over 160 peer-reviewed publications, received over 17,800 citations (Google Scholar), and authored/co-authored seven book chapters. He has a Hirsch Index of 69 (Google Scholar), which is a very high value within his field. He has been recognized with several awards including the Alexander von Humboldt Foundation Georg Forster Research Prize, 2007 Australian Academy of Technological Sciences and Engineering Crawford Fund "Derek Tribe Award Medal",

the IFA-International 2005 Crop Nutrition Award and the Scientific and Technical Research Council of Turkey Science Prize. Since 2012, he has been an elected member for "The Academy of Europe" and "The Science Academy" in Turkey. Very recently, he has received the World Academy of Sciences Prize, 2016 in Agricultural Sciences.

Q. What are your thoughts on the future challenges for agronomy?

One of the points we should focus on in the future is related to the plant, we focus a lot on soil. We study potassium dynamics, concentration, uptake, and leaching. Most of the research focuses on soil data and very little on plant data. Scientists and research programs should also focus on data related to plant growth and to the potassium nutritional status of the plant.

Q. What advice would you give young scientists?

I think young scientists should always dream. Without a dream or goal, it is not enjoyable research. They should be focused. My observation today is that many scientists focus on too many topics. They should always have an idea and they have to listen to people and to farmers. The research they are doing should have some impact on society and the environment. Applied science is very important, we should not overlook it, but part of the science should have some value to the end user.

•••

The IPNI Science Award is intended to recognize outstanding achievements in research, extension, or education; with focus on efficient management of plant nutrients and their positive interaction in fully integrated cropping systems that enhance yield potential. Dr. Cakmak receives a special plaque along with a monetary award of US$5,000. A committee of noted international authorities selects the recipient.

Private or public sector agronomists, soil scientists, and crop scientists from all countries are eligible for nomination. More information about the IPNI Science Award is available at http://www.ipni.net/awards. BC

4R Potassium Management in Apple Production in North China

By Shutian Li, Yan'an Tong, Rongzong Cui, and Ren Wang

Although selection of K fertilizer source often shows little agronomic differences, **demonstrated gains due to better rate, timing, and placement of K are clearly worth exploring** for the apple growers in northern China.

Apple orchard in Shaanxi. Apple is one of the main fruits in China, with a production area of about 2.3 million (M) ha producing 40 M t, which accounts for 25% of the total national fruit production.

In northern China, the provinces of Shaanxi, Shandong, Hebei, Henan, Gansu, and Liaoning contribute to more than 80% of the country's total apple orchard area (MOA, 2013) making it one of the main cash crops for the region's farmers. Potassium is a very important nutrient for apples because of its well-known effects on fruit quality and storage.

Potassium's role as a "quality element" is well known. If soil K is limiting, plant processes including photosynthesis, respiration, sugar translocation, and numerous enzymes are impaired, which ultimately impacts the quality of any harvested product. In apple, sufficient K supply can increase fruit sugar content, improve fruit color and flavor (Wang et al., 2002; Zhang et al., 2007). Potassium also has significant impacts on apple fruit hardness, soluble solids, and titratable acid (Zhang et al., 2014) and shelf life (Yoshioka et al., 1989). In this latter case, maintaining an adequate and balanced soil K supply in apple orchards is critical. Excessive K input can limit the plant-availability of Ca (a competing cation), which is a condition associated with the development of the physiological fruit disorder called "bitter pit".

Based on the research data conducted in northern China by the IPNI China program, 4R K management (i.e., applying the right K source, at the right rate, time, and place) has an important role to play in enhancing the effectiveness of K inputs to the region's apple orchards.

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; Ca = calcium; KCl = potassium chloride; K_2SO_4 = potassium sulfate; FYM = farmyard manure.

Right Source

The most commonly used K sources in China's apple orchards are KCl and K_2SO_4. KCl commonly has a lower market price than K_2SO_4, and when applied at the same rate can reduce input cost and improve economic benefit. Besides the economic advantage, apple often responds to KCl. Studies in Shandong showed that in a 15-year old orchard, basal application of KCl at 0.6 kg K_2O/plant in spring increased fruit yield by 17% compared with a no K application (Tang, 2007). A five-year experiment in Shaanxi indicated that basal application of KCl at 0.25 kg K_2O/plant in the fall increased fruit yield of a 13-year old orchard by 22% and also improved fruit hardness and soluble solid content (Zhao et al., 2009).

Comparing KCl and K_2SO_4, Chen et al. (2006) indicated that K_2SO_4 had a better effect on fruit yield than KCl at the same rate of K_2O, while Tang (2007) showed that K_2SO_4 produced less first-class fruit, and fruit had less soluble sugar and a higher sugar/acid ratio compared with trees receiving KCl. Field research from IPNI in three locations in China has found no significant difference between these K sources on fruit yield or quality (**Table 1**).

Right Rate

Apple researchers in China generally recommend a 2:1:2 ratio for $N:P_2O_5:K_2O$ application, but in practice the recommended rate for apple is complicated by a number of factors including tree-age, yield potential, tree density, climate conditions, soil nutrient status, and water management. Thus, recommendations vary significantly by region. The general recommendation for Fuji orchards has been based on the nutrient requirement needed to produce 100 kg fruit (Xi, 2006), i.e., 0.8-0.56-0.64 kg $N-P_2O_5-K_2O$/ha plus 200 kg FYM/ha. Therefore in practice, a fruit yield of 60 t/ha would require about 384 kg K_2O/ha plus 120 t/ha of manure. In a study in the Weibei arid region of Shaanxi, Liu et al. (2008) found application of 500-250-417 kg $N-P_2O_5-K_2O$/ha for Fuji orchards yielding 30 t/ha to be balanced. In Shandong, Hao et al. (2012)

Table 1. Effect of K sources on fruit yield and quality.						
Location	K source	Fruit yield, t/ha	Titratable acid, %	Firmness, kg/cm^2	Soluble solid, %	K conc., g/kg dry weight
Liaoning	-K	56.5 b	0.37 a	7.90 b	11.30 b	7.07 a
	KCl	66.5 a	0.37 a	8.40 a	12.60 a	6.73 a
	K_2SO_4	66.1 a	0.36 a	8.60 a	11.50 b	6.93 a
Shandong	-K	46.1 b	0.83 a	7.22 a	10.80 b	4.45 b
	KCl	48.4 a	0.78 a	7.41 a	12.04 a	5.18 a
	K_2SO_4	48.7 a	0.78 a	7.17 a	11.88 a	5.47 a
Shaanxi	-K	66.7 b	0.27 a	11.08 a	12.70 a	6.63 a
	KCl	90.0 a	0.30 a	9.84 a	12.30 a	7.46 a
	K_2SO_4	80.1 a	0.24 a	9.42 a	11.46 a	6.74 a

Notes: Two-year average fruit yields. Fertilizer K applied at the equivalent rate of 0.30 kg K_2O/plant. Quality indices were tested in the second year of the experiments. Numbers followed by different letters in the same column at the same location indicate significant difference at $p<0.05$.

A case of bitter pit in apple, caused by an imbalanced supply of Ca relative to K.

recommended 0.7-0.35-0.7 kg N-P_2O_5-K_2O/ha for each 100 kg of fruit production.

Application rates can also be based on estimates of K removal by fruits, leaves, and pruned branches. Examining orchards in Liaoning, Shandong, and Shaanxi, IPNI found the two-year average K removal by these respective plant parts to fall between 208 to 274, 74 to 84, and 116 to 148 kg K_2O/ha/yr, respectively. Theoretically, to keep balance, at least this amount of removal should be compensated for. However, in low K fertility soil, the K recommendation should be higher than removal in order to adequately buildup soil K concentrations.

Field trials with various rates of potash can also be used to determine the right rate of K. IPNI studies in Liaoning, Shandong, and Shaanxi found the economic optimum application rate for KCl to be 658, 400, and 583 kg K_2O/ha (i.e., 0.79, 0.45, and 0.35 kg K_2O/tree), while the rate for maximum yield was 674, 445, and 583 kg K_2O/ha (i.e., 0.81, 0.50, and 0.35 kg K_2O/tree), respectively (**Figure 1**). These results support the work by Jin et al. (2007), who found 600 kg K_2O/ha (0.36 kg K_2O/tree) to be appropriate in a 10-year Fuji apple orchard in Shaanxi. Similarly, Feng (2015) found 660 kg K_2O/ha (0.44 kg K_2O/tree) could produce maximum yield for Fuji apple in Liaoning.

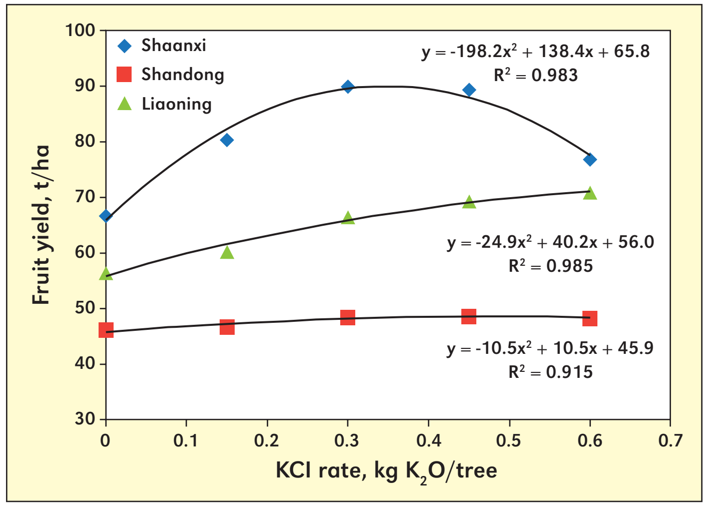

Figure 1. Relationship between the KCl application rate and apple (Fuji) fruit yield. IPNI Collaborative Research.

Right Time

Generally, apple trees take up soil nutrients after harvest until winter, storing these reserves to guarantee sufficient nutrient supply for young sprouts early the following year. Nutrient uptake increases after flowering and reaches a peak between fruit expansion and maturity (Fan et al., 2007). Thus, K nutrition during the late stages of growth are critical to fruit yield and quality.

Applying half or all of the K recommendation during the flowering and fruit expansion stages can produce more fruit than if the total K application occurs at the start of the season as a basal application (**Table 2**). A separate study by Lu et al. (2015) also found that split application of K increased fruit yield by 20 to 28% compared with a single basal application, and that the right time for K application was a 50:50 split applied first as basal application and then at the fruit expansion stage. However, large K applications late in the season can have a negative effect by reducing fruit Ca content, increasing the fruit K/Ca ratio, and reducing fruit firmness (**Figure 2**). In research by IPNI, this effect was most apparent in Liaoning and Shaanxi (**Table 2**). This information highlights the need to monitor Ca nutrition when applying K fertilizers as is may be necessary to supplement orchards with Ca.

Right Place

The horizontal root system of apple trees is mainly distributed within the area occupied by the tree crown, with roots distributed within a 20 to 50 cm depth. This is favorable for nutrient uptake when fertilizers were applied in the root zone. In China's orchards, three approaches are used for fertilizer placement including: (i) a circular furrow, (ii) a strip furrow, and (iii) radial fertilization from the tree trunk. The correct application method is dependent on tree age, density, fertilizer source, and time of application. For young orchards with less density, the recommendation is a basal application of fertilizer mixed with decomposed manure, which is placed in a circular furrow 40 to 50 cm wide, 30 to 40 cm deep, and 20 to 30 cm away from tree crowns. For high density orchards, strip furrow application is recommended using a 40 to 50 cm wide and 40 to 50 cm deep furrow placed along the tree row 20 to 30 cm away from tree crown. The furrow is usually done

Table 2. Effect of KCl application time on fruit quality indices.						
Location	Timing of K application	Fruit yield, t/ha	Firmness, kg/cm^2	K conc., g/kg dry weight	Ca conc., g/kg dry weight	K/Ca ratio
Liaoning	-K	58.0 c	7.90 d	7.07 a	1.03 a	6.9
	100% B	68.4 b	9.00 a	6.80 b	0.93 a	7.3
	50% B+50% FE	72.4 a	8.80 ab	7.03 a	0.93 a	7.6
	50% FL+50% FE	70.3 ab	8.60 bc	7.03 a	0.97 a	7.2
	100% FE	68.1 b	8.57 c	6.83 b	0.50 b	13.7
Shandong	-K	45.4 b	7.26 a	5.07 c	0.47 ab	10.8
	100% B	48.2 a	7.30 a	5.33 ab	0.43 bc	12.4
	50% B+50% FE	49.7 a	7.30 a	5.48 a	0.43 ab	12.7
	50% FL+50% FE	48.1 a	7.30 a	5.26 bc	0.39 cd	13.5
	100% FE	47.1 a	7.32 a	5.27 b	0.38 d	13.9
Shaanxi	-K	67.0 b	11.08 ab	7.63 a	1.17 a	6.5
	100% B	68.1 b	10.95 ab	9.01 a	0.97 ab	9.3
	50% B+50% FE	77.7 a	11.31 a	7.52 a	1.02 a	7.4
	50% FL+50% FE	84.1 a	10.13 ab	8.01 a	1.15 a	7.0
	100% FE	82.6 a	8.97 b	8.56 a	0.71 c	12.1

Notes: Two-year average fruit yields. B: basal application, FE: fruit expansion, FL: flowering. Numbers followed by different letters in the same column at the same location indicate significant difference at $p<0.05$. IPNI Collaborative Research.

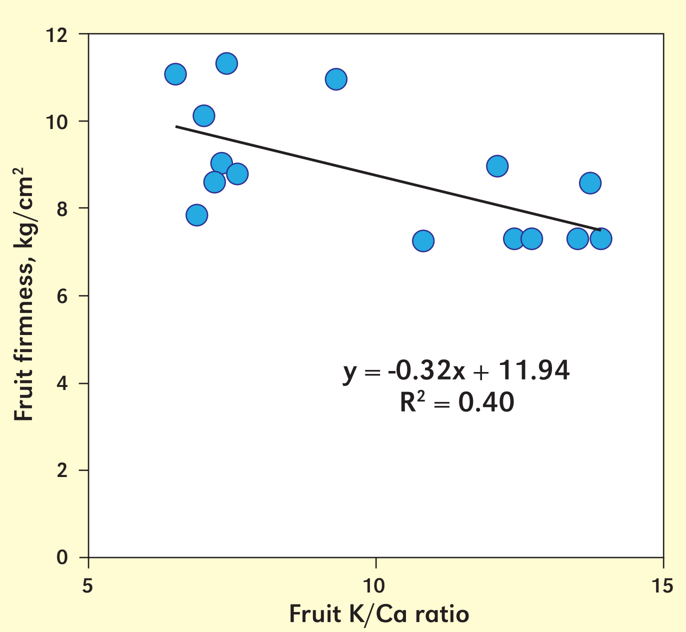

Figure 2. Relationship between fruit K/Ca ratio and apple fruit firmness. IPNI Collaborative Research.

by a trenching machine. For full-grown trees with low density, radial fertilization is recommended using 3 to 6 radial furrows around the tree trunk (20 to 40 cm wide, 20 to 40 cm deep, with a 0.5 to 1.0 m length), placed 50 cm away from trunk. In all three fertilizers can be applied in shallow soil layer (20 to 30 cm) when topdressing. Care should be taken to avoid damage to tree roots when digging, and the furrows should be covered with soil after fertilizer application, and then irrigated.

Fertigation is another method to apply fertilizer K. Fertigation, through drip irrigation, can effectively apply soluble nutrients and has been shown to improve nutrient and water use efficiency. Raina et al. (2013) found 35% higher fruit yields and a 25% savings on irrigation water through drip fertigation compared to conventional fertilization with surface flood irrigation. It is recommended that orchards in northern China convert to fertigation based on the present water shortages and low fertilizer use efficiencies that are achieved with traditional irrigation practices.

Foliar application can also be used to supplement the supply of K at different growth stages. Foliar application of K_2SO_4 with other nutrients like Ca during the fruit expansion stage is a popular means to improve fruit yield and quality, and to prevent physiological diseases like bitter pit.

Summary

This article demonstrates the importance of K nutrition in apple production. There is little difference in the agronomic effectiveness of the commonly applied K sources. However, the right rate and balanced use of K fertilizer split between a basal pre-plant application and a topdressing during fruit expansion resulted in more yield and an improved quality apple. Proper K fertilizer placement depends on tree-age and planting density. Careful consideration of K management based on 4R principles can support higher yield and quality of apple. BC

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References

Chen, W., S. Qu, G. Chen, and Z. Zhang. 2006. Jiangsu Agri. Sci. 5:165-166 (in Chinese).

Fan, H., Y. Tong, S. Lu, and R. Liu. 2007. J. Northwest A&F Univ. 35:168-172 (in Chinese).

Feng, Z. 2015. Anhui Agri. Sci. Bull. 21: 56-57 (in Chinese).

Jin, H, L. Zhang, B. Li, M. Han, and X. Liu. 2007. Acta Agri. Boreali-occidentalis Sinica 16:100-104 (in Chinese).

Liu R., Y. Tong, Y. Gao, and Y. Zhao. 2008. J. Northwest A&F Univ. 36:135-140.

Lu, Y., X. Yang, R. Li, S. Li, and Y. Tong. 2015. Chinese J. Appl. Ecol. 26:1179-1185 (in Chinese).

MOA. 2013. China Agriculture Statistical Report. China Agri. Press.

Raina J.N., S. Suman, P. Kumar, and R.S. Spehia. 2013. Commun. Soil Sci. Plan. 44:2560-2570.

Tang, X. 2007. Northern Hortic. 10:38-39 (in Chinese).

Wang, Q., W. He, J. Guo, X. Huang, S. Jiao, and Y. He. 2002. J. Fruit Sci. 19:424-426 (in Chinese).

Xi, R.Q. 2006. Masters Thesis. China Agri. Univ.

Yoshioka, H., K. Aoba, M. Fukumoto, and K. Fujimoto. 1989. J. Japan. Soc. Hort. Sci. 58:475-481.

Zhang, D.J., M. Zhao, S. Han, W. Gao, L. Luo, and L. Zheng. 2014. Acta Hortic. Sinica. 41:2179-2187 (in Chinese).

Zhang, L.X., L.S. Zhang, B. Li, and M. Han. 2007. J. Northwest Forestry Univ. 22:111-115 (in Chinese).

Zhao, Z., Y. Tong, Y. Gao, and Y. Fu. 2009. Plant Nutri. Fert. Sci. 15:1130-1135 (in Chinese).

A Certification Program for 4R Nutrient Stewardship

By Tom Bruulsema

The implementation of principles of 4R Nutrient Stewardship using a collaborative approach is helping to guide producers to adopt practices that benefit both their profitability and the health of Lake Erie.

Issue

Water quality and P loading have been connected issues for Lake Erie for decades. Lake Erie provides drinking water for millions of people, produces more than half the fish in the Great Lakes, and attracts many tourists. Algal blooms caused by nutrient loading threaten drinking water quality, beach quality, and coastal recreation. In addition, the nutrient loadings and algal blooms connect to a bottom water hypoxia issue in the Central Basin of the lake (IJC, 2014).

Programs established in the 1970s and 1980s have successfully reduced total P loadings per year from over 25,000 t in 1969 to 11,000 by the early 1980s (**Figure 1**). The majority of these loading reductions were achieved through controls on point sources such as sewage treatment plants. Increased use of conservation tillage on cropland is among the practices considered to have contributed to load reductions from nonpoint sources observed by 1995 (Richards et al., 2002).

Starting in the early 2000s, however, the western basin of Lake Erie began showing a resurgence of algal blooms similar to those that were frequent in the late 1960s to the early 1970s. In 2011, an algal bloom of unprecedented scale was documented by satellite monitoring. It became apparent that the increasing trend in bloom severity and extent paralleled an observed increase in loadings and concentrations of dissolved phosphate in the tributaries that drain a large area of productive cropland in northwestern Ohio and parts of Indiana and Michigan (**Figure 2**). Reasons for the increased phosphate in the tributaries are not fully understood, but it is recognized that several causes are probable. One major cause is changes in weather patterns, with increased frequency of intense rain in late fall and early winter, and increased river flows.

Nonpoint sources are estimated to contribute 71% of the dissolved and 89% of the total annual P load in the western Lake Erie watershed (Maccoux et al., 2016). Agriculture is considered a large source since it occupies over three quarters of the land area. Crop yields and P removed with harvested products have increased, but P application rates have not increased substantially during this period. As a result, the cropland P balance is changing from a small surplus to a small deficit (Jarvie et al., 2017). Aggregated soil sampling data indicates that the levels of P in the watershed's soils have not increased and instead the frequency of soils deficient in P has increased. In fact, Ohio soils are lower in available P than the soils of other states and provinces in the vicinity (Bruulsema, 2016). Practices such as tile drainage, broadcast application

Abbreviations and notes: P = phosphorus.

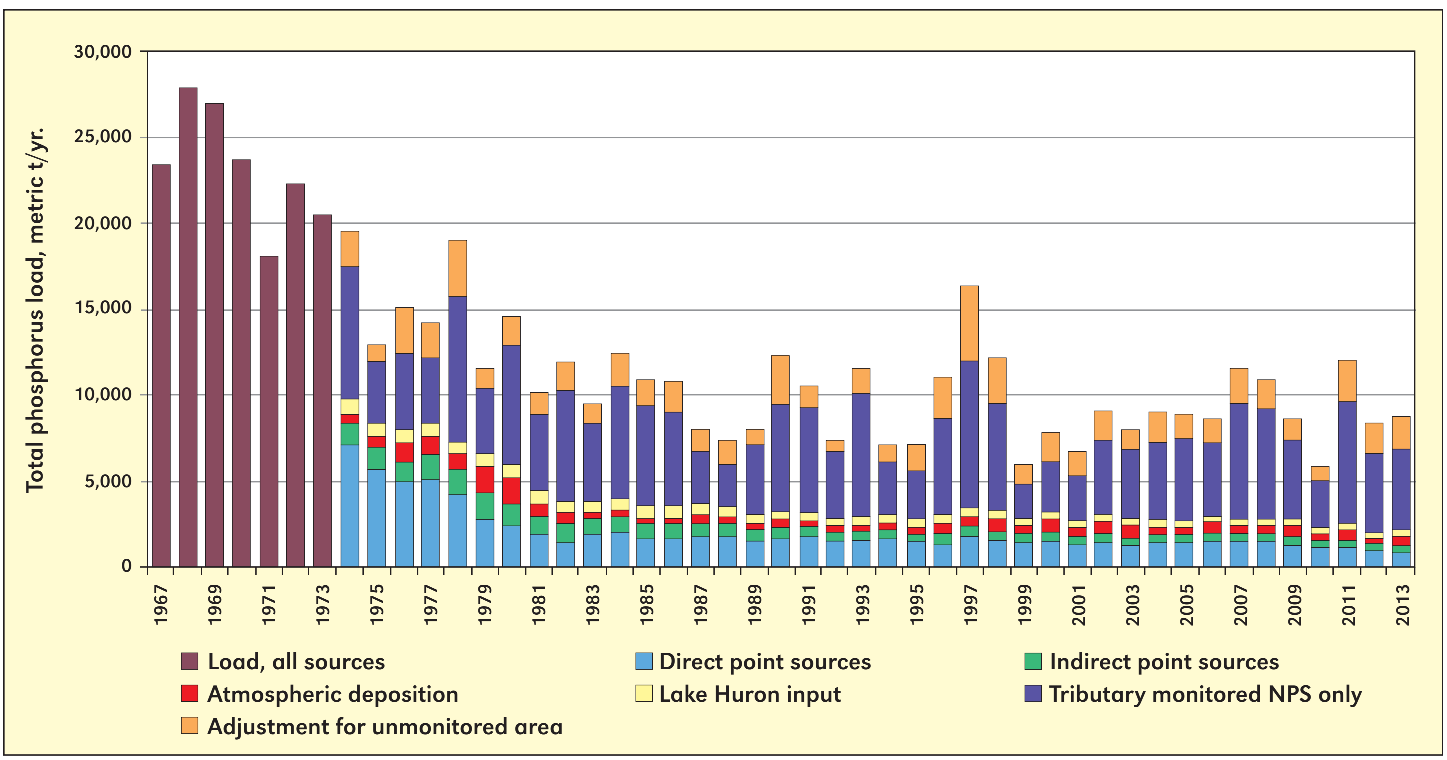


Figure 1. Total phosphorus loads to Lake Erie by source type (1967-2013). No source type attribution data are available prior to 1974. Source: Maccoux et al. (2016).

Figure 2. Much of the western Lake Erie watershed drains into the western basin of Lake Erie, which experienced increasing algal blooms from the mid-1990s to 2015. Source: http://4rcertified.org/about/

of fertilizer, and conservation tillage are identified as possible contributors to the trend in increased losses, but there are few consistent datasets on the frequency of these practices across the watershed over the time period.

Actions

By 2010, Ohio researchers from Heidelberg University had been reporting increases in loads and concentration of phosphate in the Sandusky and Maumee rivers, two of the major tributaries monitored in their water quality sampling program. The Andersons, a large agricultural retail business headquartered in Maumee, Ohio, began discussions with these scientists to better understand the issues. Recognizing that a large part of their business was located in the watershed, they became engaged, even to the extent of financially supporting the program monitoring the river P loads. Around the same time, the North American fertilizer industry was developing the concept of 4R Nutrient Stewardship—the application of the right source of nutrients at the right rate, right time, and right place. Working with the Nature Conservancy, The Andersons invited other local agricultural retailers, fertilizer industry associations, government agencies and environmental organizations to come together, with the aim of developing a specific implementation of 4R Nutrient Stewardship to change and document nutrient application practices toward reducing P losses. Following multiple engagement sessions, the stakeholders developed and agreed to support a voluntary program which became known as the Western Lake Erie Basin 4R Nutrient Stewardship Certification Program.

The program is directed at agri-retailers, and provides guidelines with criteria regarding the training of their staff, record keeping, on-farm recommendations and provided application services. Each participating retail location is audited to ensure consistency with the 41 criteria in the program. Regarding nutrient recommendations and applications, criteria include all plant nutrients, but are focused on practices relevant to reducing P losses. The criteria relate to source, rate, time, and place of nutrient application.

Source - they encourage utilization of all nutrient sources available to the producer, including manure, and appropriately considering the amounts of P available in these sources.

Rates - are based on soil testing and crop yield potential, and are not to exceed the recognized recommendations of the land grant university, unless the producer has documented results from on-farm adaptive research justifying a difference.

Timing - they assure that nutrients (including fertilizers, manures, and other sources) are not applied on soils that are frozen or snow-covered, and that surface broadcast applications are not made when large rainfall events are in the weather forecast.

Placement - they encourage injecting or banding P sources below the soil surface, and using variable rate applications accounting for within-field variability in soil P availability and expected removal of P by the crop.

It was recognized that while most of the practices listed above have been shown to reduce P losses while maintaining the opportunity to continue increasing crop yields, the knowledge base was insufficient to quantify the total reduction of P loss expected at the watershed scale, nor the amount contributed by each practice. Thus, the industry simultaneously agreed to support, through a 4R Nutrient Stewardship Research Fund, a project aimed at assessing the changes in practices and the resulting impacts on water quality.

Early Results

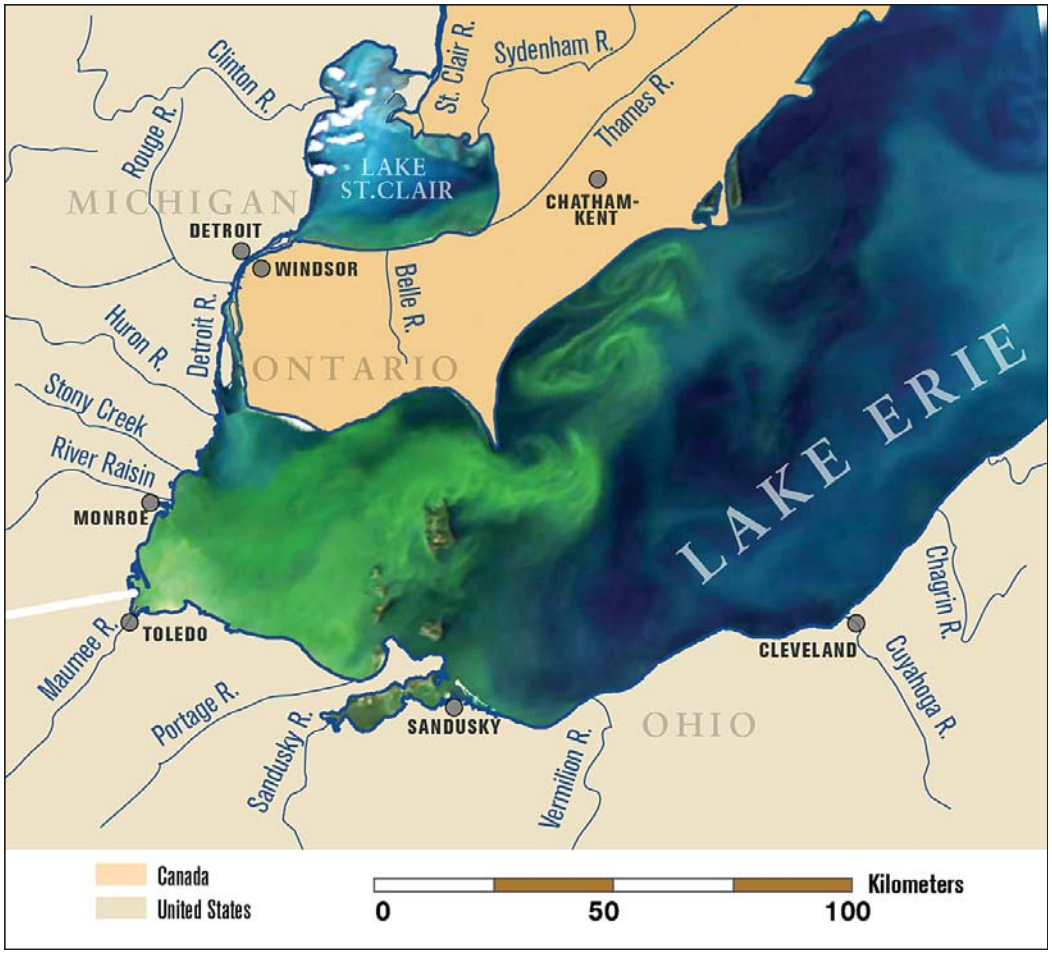
Since the program has only been in place for two years, it is too early to see direct impacts on water quality in Lake Erie. The approach, however, has demonstrated actual and potential benefits to the participating stakeholders.

The 4R certification program was launched in March 2014, though educational outreach to retailers had been underway since 2012. In its first two years, 30 retailers were certified. Through their producer customers, the reach of the certified retailers extends to over two million acres of cropland, including almost 40% of the agricultural land in the watershed (Vollmer-Sanders et al., 2016). Weather events in 2013 and 2015 featured unusually large amounts of rain in June and July, resulting in increased P loads and concentrations in the tributaries, and large algal bloom events. Against the backdrop of large weather effects, it is not possible to say as yet whether practice changes have been or will be effective in achieving the 40% load reduction agreed to by the collaborating federal, state, and provincial governments of the entire Lake Erie watershed (Government of Canada, 2016). Edge-of-field research on farm fields, however, is beginning to document efficacy of rate, time, and place practices in reducing losses. The research, initiated in 2014 and funded to continue through 2019, has documented the importance of losses through subsurface tile drains, and the connection to surface-placed P inputs by macropore flow through the soils.

Agri-retailers are experimentally introducing equipment that places the commonly used granular forms of P fertilizer in the soil while retaining residue cover on the soil—combining the benefits of conservation tillage in limiting losses of particulate P while using placement that limits loss of the dissolved form. This equipment can also apply at variable rates within the field, matching the P supply to crop need (Reese, 2014).

Conclusions

The value of the program was demonstrated during a widely publicized "do not drink" advisory issued for the City of Toledo's water supply in August of 2014. While the program was not yet at a stage to have impacted P losses or algal blooms, the many stakeholders involved were able to provide consistent messages about the efforts being made to address the issue. Subsequent public pressure for action resulted in the state of Ohio passing two legislative bills that made some aspects of the voluntary 4R program mandatory for all producers. Collaboration in developing the guidelines nevertheless provided benefits for all involved. Government agencies were able to get better buy-in to the regulations since they had been developed with stakeholder input. Retailers were well positioned and informed, enabling them to support their producer customers with assurance of regulatory compliance.



Lake Erie algal bloom on September 3, 2011 (overlaid on a map of the lake and its tributaries) about six weeks after its initiation in the lake's western basin. On this date, it covered the entire western basin and began to expand into the central basin where it will continue to grow until October. Source: Michalak et al. (2013).

One remaining issue of uncertainty surrounds conservation tillage and its impact on P loading within the watershed. Incorporation or sub-surface injection of applied P is known to reduce loss risks for dissolved P, but the associated increase in soil disturbance may increase losses of particulate P through erosion. Additionally, owing to the large influence of weather on annual loads of P in the tributaries, many years may be required to detect the effect of this and other programs being implemented to reduce P loading from nonpoint sources.

Acknowledgements

Appreciation is expressed to reviewers Chris Henney, Lara Moody, and Carrie Vollmer-Sanders. BC

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References

Bruulsema, T.W. 2016. Better Crops with Plant Food 100(2):4-6.

Government of Canada. 2016. Governments of Canada and the United States Announce Phosphorus Reduction Targets of 40 Percent to Improve Lake Erie Water Quality and Reduce Public Health Risk. http://news.gc.ca/web/article-en.do?nid=1035469

IJC (International Joint Commission). 2014. Report of the Lake Erie Ecosystem Priority. http://www.ijc.org/en_/leep/report

Jarvie, H.P., L.T. Johnson, A.N. Sharpley, D.R. Smith, D.B. Baker, T.W. Bruulsema, and R. Confesor. 2017. J. Environ. Quality http://dx.doi.org/10.2134/jeq2016.07.0248

Maccoux, M.J., A. Dove, S.M. Backus, and D.M. Dolan. 2016. J. Great Lakes Res. http://dx.doi.org/10.1016/j.jglr.2016.08.005

Michalak, A.M. et al. 2013. Proc. Nat. Acad. Sci. 110:6448-6452.

Richards, R.P., D.B. Baker, and D.J. Eckert. 2002. J. Environ. Qual. 31:17-24.

Reese, M. 2016. Ohio's Country Journal. http://4rcertified.org/2016/10/4rs-one-pass/

Vollmer-Sanders, C., A. Allman, D. Busdeker, L.B. Moody, and W.G. Stanley. 2016. J. Great Lakes Res. http://dx.doi.org/10.1016/j.jglr.2016.09.004

Fertilizer Placement Boosts Crop Yields and Nutrient Recovery

By Robert Mikkelsen

The principles of 4R Nutrient Stewardship involve using the right nutrient source, at the right rate, at the right time, and in the right place.

Fertilizer placement is one of the essential components of crop production, but it does not always receive the attention it deserves.

A recent publication by Nkebiwe et al. (2016) reviewed 1,022 datasets from around the world within a process called a "meta-analysis" to get a broad view of potential advantages of subsurface fertilizer placement compared with fertilizer applied to the soil surface. This brief summary only touches on a few of the key points highlighted in their full paper.

There has been considerable research done on optimal fertilizer placement to boost nutrient recovery and crop yields, and to make them more competitive against weeds. However, studies have shown conflicting results, making it challenging to understand general trends. Terminology can be confusing because "fertilizer placement" refers to a variety of techniques used to place nutrients to a small area on the surface or in the subsurface soil. In addition to crop growth, fertilizer placement decisions will also influence environmental parameters such as nitrate leaching, gaseous loss of nitrous oxide and ammonia, and P runoff.

Decisions related to fertilizer placement need to consider many factors related to crop nutrient demand and potential losses. As examples, split applications of fertilizer may better match crop demands for key growth periods, but require greater labor and energy costs. Placement of fertilizer in the seed zone may be advisable for some crops, but high rates of fertilizer applied near seeds may damage the young plants. Surface application of N fertilizers must be done carefully to avoid elevated losses of ammonia. Starter fertilizer (applied 5 cm (2 in.) sideways and 5 cm. below the seed) helps sustain nutrient availability during early crop growth. Subsurface-applied fertilizer may be placed relatively shallow 5 to 10 cm or deep (>10 cm) depending on the objective. When fertilizer is applied relatively deep in the soil, it may be more available for plant uptake during periods of drought when the surface soil has dried.

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

Crop Yield

The authors reviewed 722 datasets from 39 studies. On average, the result of subsurface fertilizer placement was a yield increase of 4%, compared with broadcast application. This yield increase ranged from 9% for potato, sugar beet, and winter wheat, 4% for maize, and no yield increase for soybeans and grass from subsurface fertilizer placement.

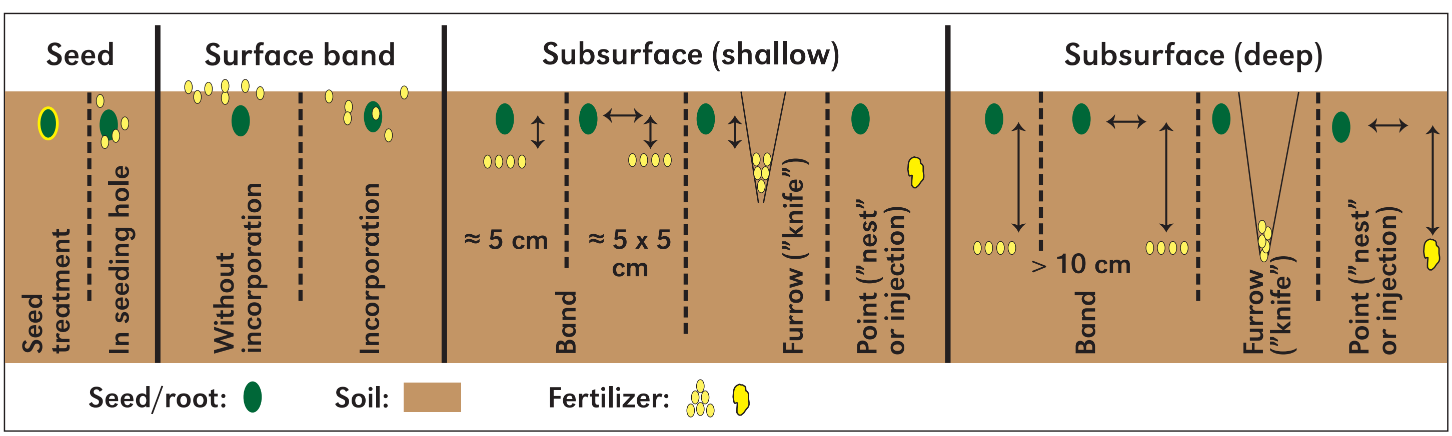
Of the 11 placement techniques analyzed, subsurface deep point injection resulted in the highest yield boost (6%) compared with surface application. The fertilizer materials most effective at increasing crop yield with subsurface placement (compared with surface application) was urea combined with soluble P (27% improved yield), ammonium with soluble P (15% improvement), urea (11% improvement), and ammonium (4%). These results are a good reminder of the yield benefits that often occur from combining urea or ammonium with soluble P fertilizer.

Plant Nutrient Concentration

When data from all crops and plant parts were combined (357 datasets), fertilizer placement techniques increased nutrient concentrations by 4%. This ranged from a 7% increase in nutrient concentration for maize when fertilizer is placed below the soil surface, to a slight decline in nutrient concentration in winter wheat, compared with surface application.

Plant Nutrient Content

Plant nutrient content refers to the quantity of nutrient accumulated in the above-ground portion of the plant. A synthesis of 235 datasets shows that overall nutrient content increased 12% when fertilizer was placed below the surface, compared with a surface application. Removing two outlier



Fertilizer placement techniques. Adapted from Nkebiwe et al., 2016.

studies boosted this to 19% increased nutrient uptake when fertilizer is strategically placed in the soil.

The trend for specific placement techniques was subsurface shallow band (15% increased nutrient content), followed by subsurface deep band (14%). Placement of ammonium (or urea) together with soluble P resulted in a consistent increase in nutrient uptake compared with either N or P alone.

Subsurface placement of fertilizers can result in increased yields, more nutrient uptake, and a higher nutrient concentration in plant tissues compared with broadcast application. This is likely due to:

1. The occurrence of high nutrient concentrations in close proximity to plant roots
2. Favorable chemical and biological changes in the rhizosphere
3. Stimulation of root growth in the vicinity of ammonium and soluble phosphate
4. Reduced nutrient loss to the environment
5. Deep placement (>10 cm) may provide nutrient access during times of drought stress

Subsurface placement of fertilizer can be a useful tool to improve farm productivity, but it must be considered for each field, crop, and nutrient. Additionally, subsurface fertilizer placement techniques require additional labor and energy, compared with surface application. The growing trend towards greater farm size can make it challenging to fertilize large fields in a timely manner when a slower application technique is used. However, the multiple advantages of this technique should be carefully considered as a part of the 4R Nutrient Stewardship strategy.

Acknowledgment

This article is a summary of the full article published by Peteh Mehdi Nkebiwe, Markus Weinmann, Asher Bar-Tal, and Torsten Müller. 2016. Fertilizer placement to improve crop nutrient acquisition and yield: A review and meta-analysis. Field Crops Research 196:389-401. BC

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IPNI Webinar Series

Throughout 2017, IPNI will continue its bi-weekly series of webinars that cover a wide range of agronomic topics. Many of these sessions focus on best nutrient management practices and principles and Certified Crop Advisers are welcome to apply for Continuing Education Credits (CEUs) that are available for qualifying sessions.

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Dr. W. Mike Stewart, Director, North America Program

Fertilizer application in Cassava: Is it Necessary?
Dr. Mirasol Pampolino, Deputy Director, Southeast Asia Program

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Dr. Steve Phillips, Director, IPNI North America Program

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2016 Crop Nutrient Deficiency Photo Contest Winners

We thank all participants for their submissions and extend special congratulations to our group of winners who, in addition to their cash award, will also be receiving our most recent USB flash drive collection featuring hundreds of images. For more details on this collection please see: http://ipni.info/nutrientimagecollection.

Our 2017 contest is almost ready to begin to accept new entries and we encourage everyone to check back regularly with the contest's website www.ipni.net/photocontest for details on how to make a submission. Best of luck!

Best Overall Image

First Prize (US$250) – Phosphorus Deficiency in Chickpea – Dr. Srinivasan Subbiah, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India

Dr. Subbiah took this close-up image of P deficiency in chickpea growing near Coimbatore. Taken during the crop's flowering stage, the deficiency appears with its characteristic purpling of leaves. Leaf purpling appeared first in the lower leaf tips and progressed along margins. Under acute conditions, the red-purple color spreads up the stems. "Plants were obviously stunted and ultimately resulted in a low yield," explained Dr. Subbiah. Root growth was also greatly reduced. The plants received no P after sowing and field had a long history of monocropped corn. Soil pH was 8.3. The soil test (Olsen-P) revealed that soluble levels of P were very low (less than 1.2 mg P/kg). Whole shoot analysis also registered a relatively low value of 0.14% P.

Nitrogen Category

First Prize (US$150) – Nitrogen Deficiency in Tobacco – Dr. Brian Whipker, Floriculture Group, Dept. of Horticultural Science, North Carolina State University, Raleigh, USA. Dr. Whipker setup a controlled study utilizing silica sand and technical grade fertilizer salts and induced this severe N deficiency in tobacco. The plant had a full array of classical symptoms. The oldest leaves turned necrotic, while the next leaf set had an overall yellowing and bleached appearance. Light green to yellow foliage occurred on young leaves just beginning to show symptoms. The upper foliage, was light green and stunted due to N being withheld.

Second Prize (US$100) – Nitrogen Deficiency in Raspberry – Ms. Cristina Pulido Gilabert, Oliva (Valencia), Spain. Ms. Pulido found this example of N deficiency being expresses on a fruit-bearing portion of the plant. The deficiency is visible within the photo frame, but not in other portions of the plant since the development of fruits exerted a higher local demand for N from the immediately surrounding area.

Abbreviations and Notes: N = nitrogen; P = phosphorus; K = potassium; Mg = magnesium; B = boron; Fe = iron; CEC = cation exchange capacity.

Phosphorus Category

First Prize (US$150) – Phosphorus Deficiency in Corn – Mr. Jim Valent, State College, Pennsylvania, USA. Taken near Limington, Maine, USA, Mr. Valent captured this vibrant expression of P deficiency in corn (near V4 stage). His example provides an example of the impact of soil pH on P availability. Soil samples were taken both near these purple plants and other greener plants nearby. Results showed purple plants were growing in soil with lower pH and CEC, but soil test P concentrations were similar. Distinctly purple corn had low leaf tissue P of 0.16% P, which was half the values measured for green corn. Leaf Fe and Al were well above normal concentrations in the P-deficient plants.

Second Prize (US$100) – Phosphorus Deficiency in Coffee – Mr. Rodolfo Lizcano, Baraya, Huila, Colombia. Mr. Lizcano spotted this case of P deficiency on a coffee (arabica) plant in the midst of its fruit-filling stage. The crop was growing on Oxisol soil, which commonly have pH values under 5 and have a high potential for excessive Al availability ...in this case a high Al saturation of 60%.

Potassium Category

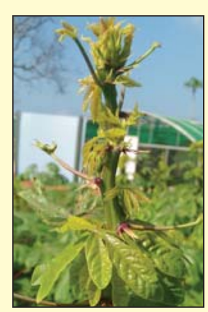
First Prize (US$150) – Potassium Deficiency in Turmeric – Mr. Udaya Kumar, Dept. Soil Sci. and Ag. Chem., Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India. Mr. Kumar provided a "crisp" example of K deficiency in a two-month-old turmeric crop near Coimbatore, Tamil Nadu. Plants showed reduced growth, shortened inter-nodes, marginal burning (brown leaf edges) and necrotic spots in the older leaves and burning marched towards younger leaves due to severe deficiency. Both the soil analysis and plant tissue analysis showed low concentrations of K (42 ppm and 2.1%), respectively. The deficiency was corrected by application of a 1% potassium sulfate (K_2SO_4) source applied by foliar spray at 14-day intervals.

Second Prize (US$100) – Potassium Deficiency in Banana – Dr. Vinicius Benites, Rio Verde, Goiás, Brazil. Dr. Benites shot this image near Mateiros, Tocantins, Brazil, where a temporarily flooded banana plantation had plants showing the distinct marginal scorching of leaves that is associated with K deficiency. "This extreme case was induced by a cation imbalance due to an excess Mg concentration in the flood waters," explains Benites.

Other Category (Secondary and Micronutrients)

First Prize (US$150) – Iron Deficiency in Cashew – Mr. Boopathi Raja, Agricultural College and Research Institute, Madurai, Tamil Nadu, India. This image from a farm field in the Madurai District of Tamil Nadu shows extensive Fe deficiency symptoms on two-year-old cashew plants. "The young leaves showed interveinal chlorosis that progressed to the plant-wide yellowing captured in this photo," explains Mr. Raja. Both soil pH (8.3) and exchangeable sodium percentage (20%) were high. Available soil Fe was 1.7 ppm (DTPA-extractable) and Fe concentration within plant dry matter was 20 ppm.

Second Prize (US$100) – Boron Deficiency in Cassava – Dr. Susan John Kuzhivilayil, Indian Council of Agricultural Research-Central Tuber Crops Research Institute, Thiruvananthapuram, Kerala, India. While scouting this 3-month-old cassava crop being grown on an acid ultisol, Dr. Kuzhivilayil spotted the typical broom-like appearance associated with B deficiency. "The apical part of the plant's leaf and stem were distinctly deformed, which limited any normal development of nearby leaves," explained Kuszhivilayil. Affected plant's will often have a healthy appearance elsewhere; however, in severe stages the crop will get stunted.



Long-term Crop Rotation Studies Remain an Invaluable Teaching Tool

By Dick Puurveen

The photograph on the following page provides a classic example of crop response to nutrient application. Crop growth improves and deficiency symptoms lessen as nutrients become less of a limitation. In this case, the image shows spring wheat plant samples taken from the long-term Breton Plots in Central Alberta, Canada. Samples were taken on June 24, 45 days after seeding (May 10). Plants are generally at the six-leaf stage, some plants are tillering depending on the nutrient input.

The classical crop rotation of the Breton Plots was initiated in 1929 on Orthic Gray Luvisol (typic cryoboralf) soil near Breton, Alberta, Canada. Two cropping systems have been studied since its initiation: 1) a two-year wheat–fallow rotation; and 2) a five-year rotation of wheat–oats–barley (underseeded with alfalfa/brome)–hay–hay. The study has fertility treatments superimposed over each crop phase of the rotation. These treatments have varied over the entire length of the study but have remained constant since 1980. Corresponding to the image (left to right) these treatments include: 1) No fertilizer (check); 2) NKS (-P); 3) NPKS (all nutrients); 4) NPS (-K); 5) NPK (-S); 6) PKS (-N) (**Table 1**).

Table 1. Fertilizer inputs (kg/ha) at time of seeding for selected treatments at the Breton Plots.

	N	P	K	S
Check	0	0	0	0
NKS (-P)	50	0	46	20
NPKS	50	22	46	20
NPS (-K)	50	22	0	20
NPK (-S)	50	22	46	0
PKS (-N)	0	22	46	20

Wheat-fallow rotation received 90 kg N/ha and the same P, K, and S rates listed.

The picture also compares representative plants from the same fertility treatment applied to each rotation. The first wheat plant (1) is from the wheat–fallow rotation; therefore, the crop is grown after a year of fallow. The second wheat plant (2) is from the 5-year rotation; therefore, grown after the year 5 forage plowdown. Although N fertilizer is not applied during either forage phase of the rotation (PKS is applied annually to all phases), the 5-year rotation benefit from N-fixing legumes during the forage phases.

Table 2. Soil nutrient analysis (ppm) from 0 to 15 cm depth prior to 5-year rotation wheat establishment on selected treatments at the Breton Plots, 2016.

	N	P	K	S	OM, %
Check	2	7	182	3	3.1
NKS (-P)	4	6	423	15	3.8
NPKS	10	>60	490	36	4.5
NPS (-K)	7	>60	128	12	4.0
NPK (-S)	<2	>60	863	8	3.7
PKS (-N)	5	>60	364	24	3.9

N as nitrate-N (modified Kelowna extraction); S as sulfate-S (0.01M $CaCl_2$ extraction).

For the 5-year rotation, soil is sampled annually in late summer only after the year 5 forage plowdown. **Table 2** shows the soil test results of the five-year rotation prior to wheat establishment. Since the wheat–fallow rotation is sampled every fifth year, corresponding samples were not collected in 2016.

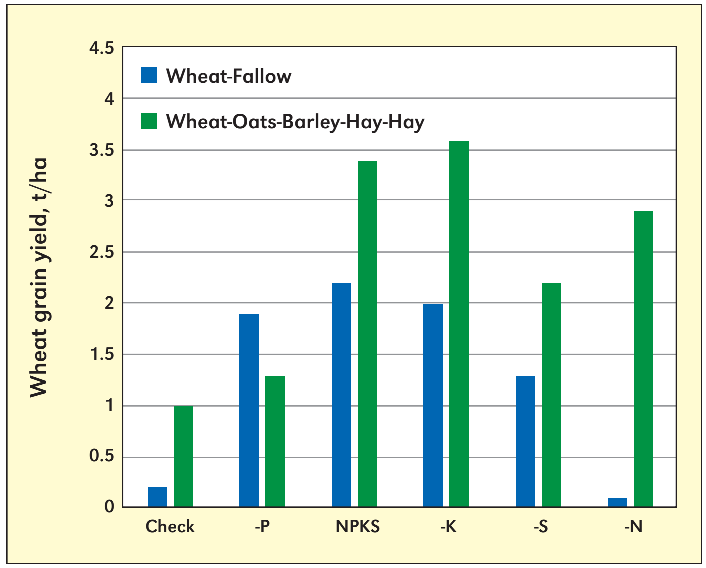


Figure 1. Wheat grain yield from selected fertilizer treatments at the Breton Plots, 2016.

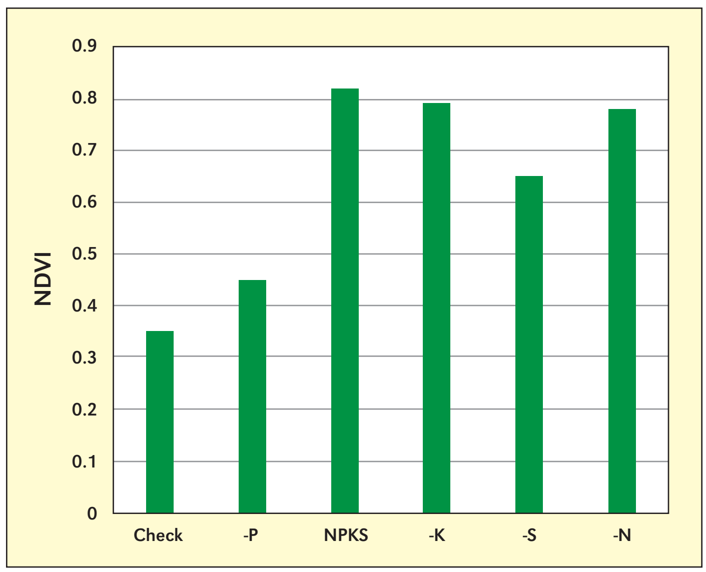


Figure 2. Average NDVI measured by Greenseeker® on the 5-year rotation wheat on July 5, 2016 (12 days after photograph was taken).

Grain yield (**Figure 1**) followed similar trends as NDVI (**Figure 2**). The benefits of legumes in rotation on yield are most notable in the -N treatment, but the -P comparison demonstrates the increased use of P with alfalfa. The NPKS treatment is generally equivalent to the -K treatment because

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; NDVI = normalized difference vegetation index.

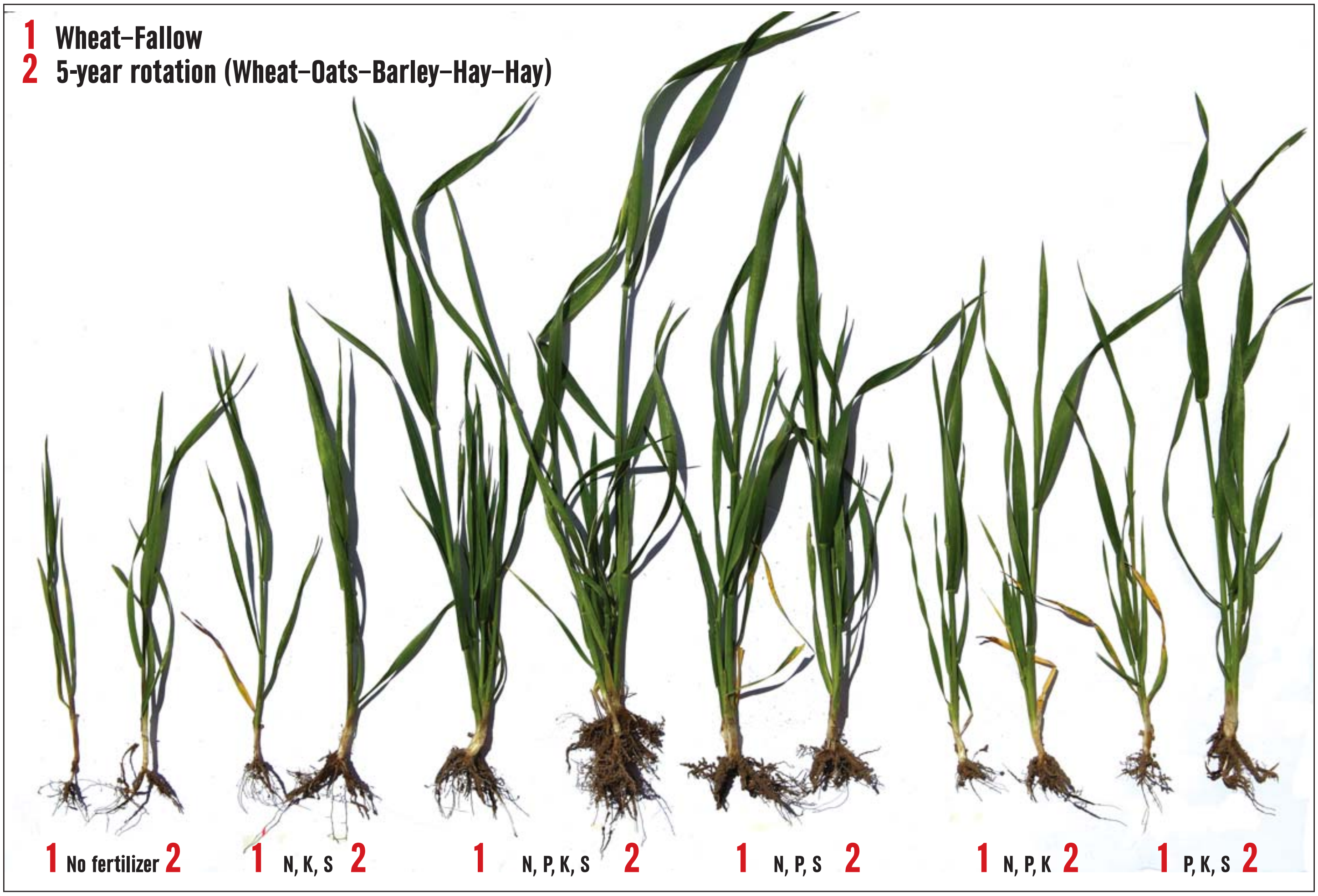


Photo by Dick Puurveen, Department of Renewable Resources, University of Alberta.

Table of notes and observations from wheat plants sampled from the Breton long-term study.	
No fertilizer (Check)	Plants shows poor root development. Plants are severely stunted and spindly. No tillers. Plants are yellow throughout, with no visible necrosis. Wheat grown in rotation with legumes is less stunted.
NKS (-P)	Plants have better root development than check, especially in 5-year rotation with legumes, yet plants are still stunted. No tillers. Wheat grown in rotation with legumes has better root and shoot development. Purpling not evident. NDVI data shows -P plants to be generally equal to values for -N plants under the wheat-fallow rotation; however, for the 5-year rotation that includes legumes the NDVI values for -P plants are much lower than -N plants (**Figure 1**).
NPKS (Complete)	Best root development, particularly in the 5-year rotation. Plants have several tillers, tallest height, and dark green color.
NPS (-K)	Plants are second tallest, but still have excellent root development. Tiller development is good, but less extensive than the with all nutrients. Signs of necrosis on oldest leaves for plants taken from the wheat-fallow rotation.
NPK (-S)	Plants have poor root development compared to the complete, but better than check. Plants have no tillers. The plant from the 5-year rotation has better root and shoot development; however, it is also showing a higher degree of necrosis on the oldest leaves.
PKS (-N)	These plants show the largest contrast between the two rotations. Although both rotations do not receive any fertilizer N, a significant benefit from the inclusion of legumes is obvious for the 5-year rotation. The plowdown of forage residue, and subsequent nutrient mineralization, provides some N, and as N is mobile in the plant, this plant shows a general yellowing throughout, but little necrosis. In contrast, the wheat-fallow rotation shows classic symptoms of N deficiency, with overall yellowing and necrosis in the lower leaves.

of K-rich soil minerals, but declining K concentrations (**Table 2**) with high yields suggest that the tipping point is near. Further yield reductions occur without S, followed by P, to "bankruptcy" yield with no fertilizer. The Long-term Breton Plots continue to teach the importance of nutrient management and crop rotation. BC

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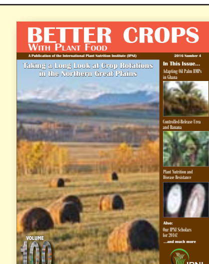
For more details on this long-term study see the article by Dyck et al., (2016) titled *Testing the Benefits of Balanced Nutrient Use and Crop Diversification on Soil Productivity and Health*, in Better Crops 100 (4):7-9.



Intensive Soybean Management: An Integrated Systems Approach

By Guillermo Balboa, Mike Stewart, Fernando Salvagiotti, Fernando García, Eros Francisco, and Ignacio Ciampitti

Ecological intensification impacted soybean yield, biomass and N uptake. Narrow row spacing, high seeding rate, other best production practices, and balanced nutrition increased partitioning efficiency for biomass, measured by seed harvest index (HI), grain N, and N HI (NHI).

Partial factor productivity of fertilizer (PFPf) increased when best production and fertilizer management practices were implemented in combination, with 19% and 28% increases under irrigated and dryland scenarios, respectively.

An integrated approach, simultaneously considering multiple management factors in a farming system, is needed for closing exploitable yield gaps.

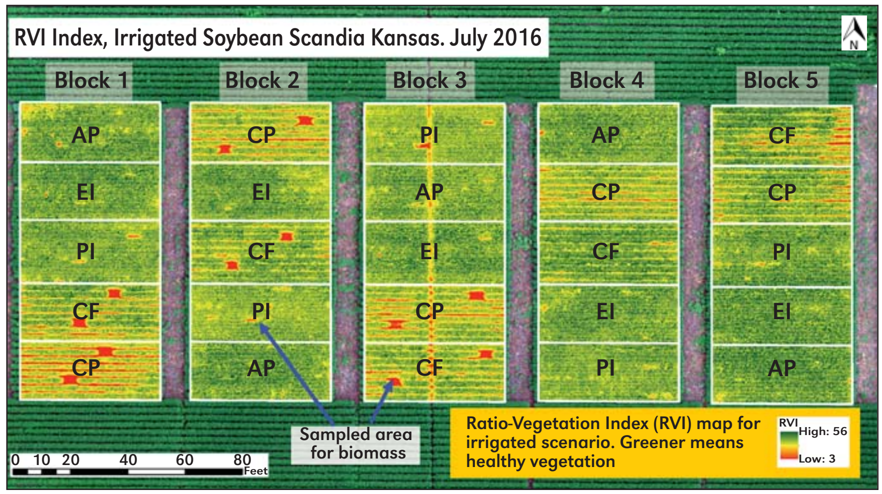
The "Yield gap" can be defined as the difference between the yield that is attainable in a region (maximum yield without abiotic or biotic stresses) and the actual on-farm yield. Selecting the best crop and nutrient management practices (e.g., genotype selection, row spacing, planting date, and nutrient 4Rs—right source, rate, time, and place), and considering their interactions with each other and with the environment (soil, weather), will directly impact the size of this gap. In recent years, several soybean studies have evaluated the effect of fertilizer applications or crop management practices individually, but research investigating the impact of these factors on seed yield in an integrated system approach is scarce.

"Liebig's Law of the Minimum" establishes that growth is controlled by the most limited resource or factor. Following this rationale, when nutrients are supplied in a complete and balanced program according to plant demand, crop yield will then be limited by some other factor such as light interception or water availability. The objective of this work was to test an integrated farming system approach that simultaneously considers both crop nutrition and crop management practices, and thereby further the understanding of cropping systems based on the concept of Ecological Intensification (Cassman, 1999).

Soybean studies were carried out in 2014 and 2015 at Scandia, Kansas, under both dryland and irrigated conditions each year. For each of the four site-years, five farming systems ranging from very low to intensive use of inputs were tested. The following treatments were evaluated: Common Practices (CP), Comprehensive Fertilization (CF), Production Intensity (PI), Ecological Intensification (EI), and Advanced Plus (AP) (**Table 1**). The main difference between CP and CF treatments was that fertilizer (P, K, and S) was added for the CF treatment. For the PI treatment, seeding rate was increased by 23,000 seeds/A over CP, row spacing was narrowed from 30 to 15 in., and no fertilizer was added. The EI treatment is a combination of CF and PI, with a seeding rate of 134,000 seeds/A, row spacing of 15 in., balanced macro plus micronutrient fertilization, and fungicide/insecticide applications. Average precipitation for both seasons was 16.3 in. and the irrigated scenario received an average of 6.9 in. of water. Lastly, AP was similar to the EI treatment, but with a more intensive (2x) use of micronutrients and fungicide/insecticide.

Detailed crop phenology (V4, V6, R1, R5, R7), seasonal plant dry biomass, nutrient concentration, and canopy coverage were evaluated in all site-years.

Harvest index (HI) and N Harvest Index (NHI) were determined as follows:



Aerial image showing differences in the Ratio-Vegetation Index [the ratio of infrared reflectance over visible red reflectance (NIR/VR)] for irrigated soybean at Scandia, Kansas. Green color is correlated with healthy growth.

Table 1. Treatment description for soybean experiment at Scandia, Kansas, average of 2014-2015 growing seasons.

Treatments	CP	CF	PI	EI	AP
Seeding rate, seeds/A	111,000	111,000	134,000	134,000	134,000
Row spacing, in.	30	30	15	15	15
Fertilization	No	(P-K-S)	No	(N*-P-K-S)	(N*P-K-S)
Micronutrients	No	No	No	1x (Fe, Zn, B)*	2x (Fe, Zn, B)**
Fungicide/Insecticide	No	No	No	1x**	2x**

CP=common practices, CF= comprehensive fertilization, PI= production intensity, EI= ecological intensification (CF+PI), AP= advanced plus. *Applied at R3. **Applied at R1 and R3. Fertilizer rates in lb N-P_2O_5-K_2O-S/A: (56-9-31-8) and (56-13-43-11) for dryland and irrigated. Treatment CF did not receive any N application.

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; B = boron; Fe = iron; Zn = zinc. IPNI Project GBL 62.

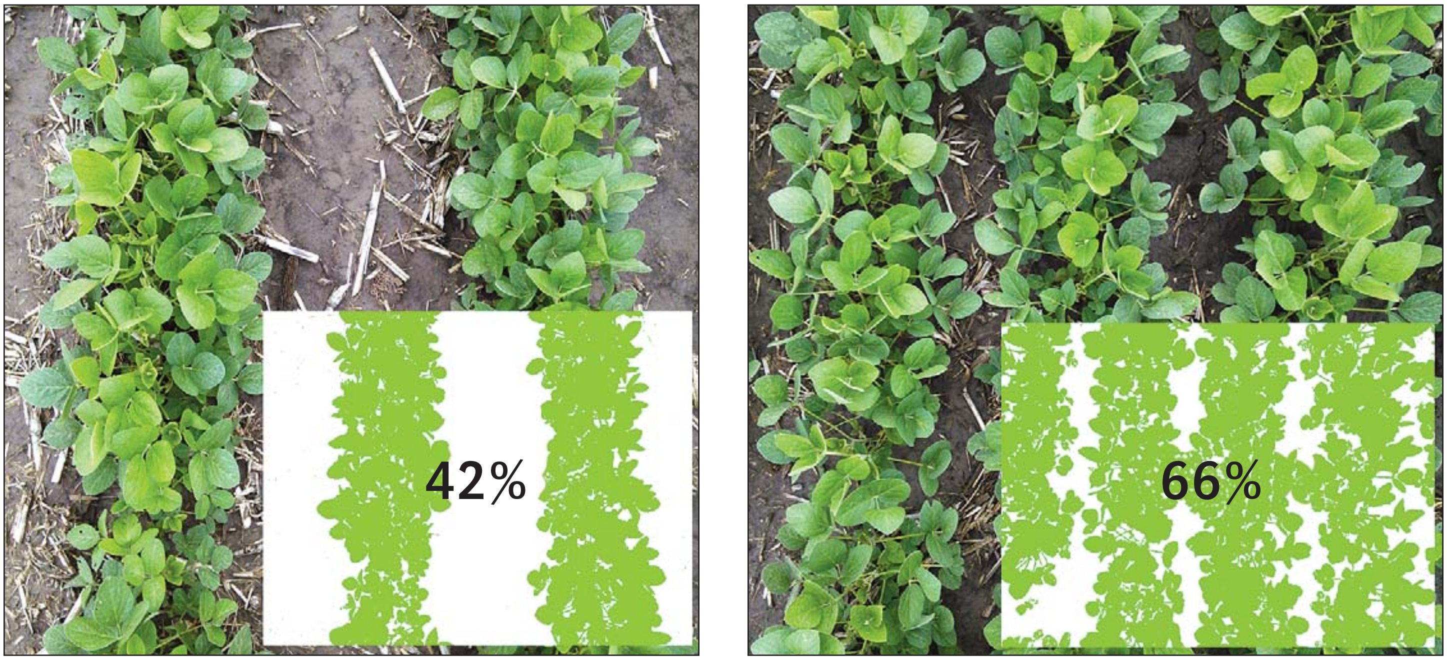


Figure 1. Soybean canopy coverage for treatment CP (left) and EI (right) at phenological stage V4 Scandia, Kansas, 2015 growing season. Image inserts and percent cover were produced using Siscob® software from EMBRAPA.

HI = Seed (lb/A) / Plant Biomass (lb/A)

NHI = Seed N Content (lb/A) / Plant N Content (lb/A)

The partial factor productivity of fertilizer (PFPf), was calculated as the ratio of yield to fertilizer applied ($N+P_2O_5+K_2O+S$) for both CP and EI.

Results

Visible differences in canopy coverage at phenological stage V4 (four-trifoliolate) in soybeans were detected by image analysis (**Figure 1**). Under irrigated conditions, canopy coverage for the CP treatment was 42%, while for the EI treatment coverage was 66%. This greater early season coverage with the EI treatment resulted in more light interception and likely increased efficiency of carbon to biomass conversion.

Seed Yield

Two-year average soybean seed yields are presented in **Figure 2**. Dryland seed yield averaged across treatments and years was 43 bu/A. The maximum average dryland yield was attained in the AP treatment (53 bu/A), but was not statistically different from the PI (48 bu/A) and EI (51 bu/A) treatments. The average of these three more intensive treatments (PI, EI, and AP) was 51 bu/A. The CP and CF treatments both yielded 31 bu/A. Thus, the exploitable yield gap calculated from this data for the dryland scenario was 20 bu/A. Although the soybean yields for the PI and EI treatments were not statistically different, the PI treatment is depleting soil nutrients and therefore risking the yield potential of future crops. In fact, in this study when corn followed soybeans, a large corn yield reduction (20 bu/A in 2015) was documented in the PI compared to the EI treatment, directly reflecting the impact of the negative nutrient balance in the soybean phase.

For the irrigated scenario, seed yield averaged across treatments and years was 69 bu/A, 26 bu/A more than the overall average under dryland conditions. Increasing production intensity by narrowing row spacing and increasing seeding rate

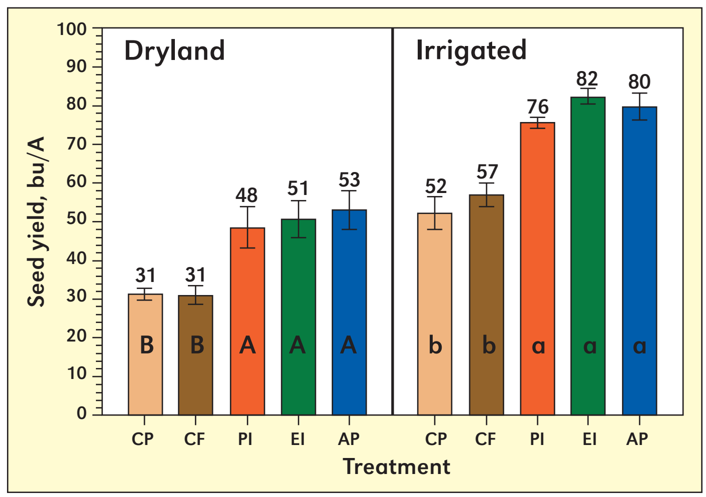


Figure 2. Soybean seed yield for dryland and irrigated conditions at Scandia, Kansas, average of 2014-2015 growing seasons. Letters within columns indicate statistical differences for seed yield ($p<0.05$).

increased yield by 24 bu/A, from 52 bu/A in the CP treatment to 76 bu/A for the PI treatment (**Figure 2**). While yields for the CP (52 bu/A) and CF (57 bu/A) treatments were numerically different, that difference was not statistically significant. The average across the lower intensity treatments (CP and CF) was 54 bu/A. The maximum irrigated yield was attained by combining the fertilizer and crop management practices in the EI treatment (82 bu/A), and although this was the highest yield, it was not significantly different from the PI (76 bu/A) and AP (80 bu/A) treatments. The average of these three more intensive treatments (PI, EI, and AP) was 79 bu/A. Therefore, the exploitable yield gap calculated from the irrigated scenario was 25 bu/A. On average, each in. of water applied produced 3.6 bu of soybean.

Under irrigated conditions the PFPf, or seed yield divided by the total quantity of fertilizer applied, was 14 (lb yield/lb

Table 2. Total biomass production, stover, and seed harvest index (HI) under dryland and irrigated conditions (Scandia, KS), average of 2014-15 growing seasons.

	Dry biomass, lb/A		Stover, lb/A		HI	
Treatments	Dryland	Irrigated	Dryland	Irrigated	Dryland	Irrigated
CP	7,516 b	9,024 c	5,667 a	5,915 c	0.25 c	0.34 a
CF	7,399 b	11,653 b	5,570 a	8,254 b	0.25 c	0.29 b
PI	9,632 a	13,759 a	6,804 a	9,247 a	0.29 b	0.33 a
EI	8,693 a	14,853 a	5,748 a	9,935 a	0.34 a	0.33 a
AP	9,356 a	14,449 a	6,281 a	9,687 a	0.33 a	0.33 a

CP=common practices, CF= comprehensive fertilization, PI= production intensity, EI= ecological intensification (CF+PI), AP= advanced plus. HI=Harvest Index. Letters indicate statistical differences (p<0.05).

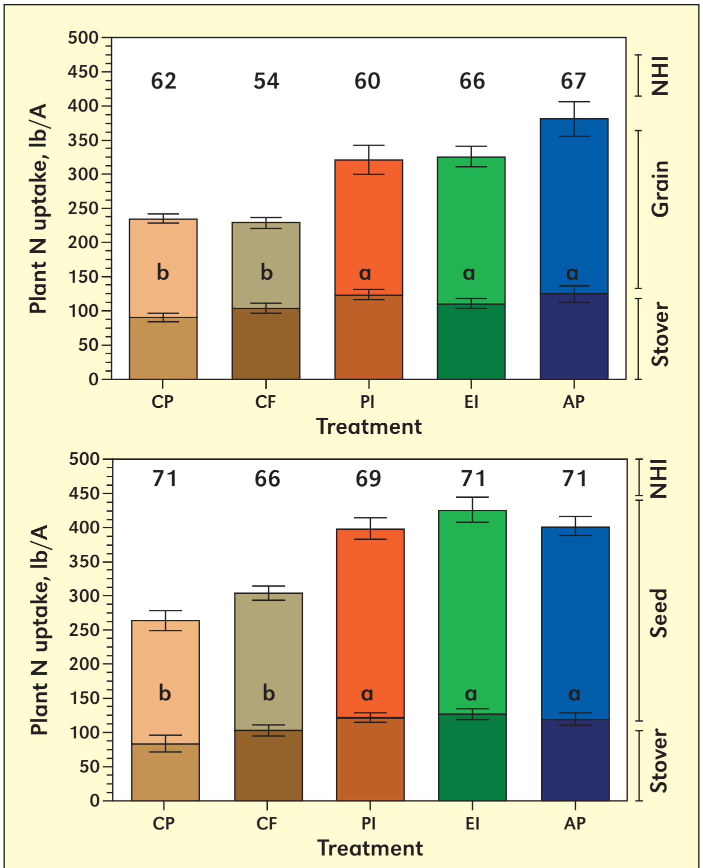


Figure 3. Plant N uptake and Nitrogen Harvest Index (NHI) for soybean treatments under dryland (top) and irrigated (bottom) environments at Scandia Kansas, average of 2014-2015 growing seasons. Letters within columns indicate statistical differences for plant N uptake (p<0.05).

fertilizer) for the CP treatment and 17 for the EI treatment. For the dryland environment, PFPf for CP was 11, and for EI it was 14. The PFPf for EI treatment was 19% greater under irrigation, and 28% greater under dryland conditions than the CP treatment. By intensifying production practices (narrow row spacing and increasing seeding rate), each unit of fertilizer added to the system was more efficient in producing seed yield.

Total Plant Biomass and Seed Harvest Index

Under irrigated conditions total biomass production averaged 12,748 lb/A, which was 50% greater than the dryland scenario (**Table 2**). The CP treatment consistently produced less total plant biomass and stover than the rest of the treatments under irrigation. Under dryland conditions, total plant biomass followed the same trend as seed yield (**Figure 2**), and treatments with more intensification (PI, EI, and AP) produced 24% (or 1,770 lb/A) more biomass than the CP-CF treatments. Under irrigation, the more intensive treatments increased biomass by 39% (or 4,015 lb/A) over the CP-CF treatment average (**Table 2**). Balanced nutrition alone (CF) under irrigation increased total biomass production by 29% (or 2,629 lb/A) relative to the CP treatment; and a 65% (or 5,829 lb/A) increase in biomass was documented when balanced nutrition was combined with the more intensive EI management.

In summary, this study demonstrated a large impact of fertilizer and crop management practices on total plant biomass production under both dryland and irrigated scenarios. As for the seed HI component, under dryland conditions, intensifying production increased yields via improvement of seed HI; while under irrigated conditions the intensification process was primarily governed via changes in total plant biomass (**Table 2**).

Total N Uptake

The increase in total plant biomass corresponded with an increase in total plant N uptake. Total plant N uptake averaged across the two seasons ranged from 230 to 380 lb/A under dryland and 270 to 425 lb/A for the irrigated conditions (**Figure 3**). For both water availability scenarios, the more intensified treatments (PI, EI, and AP) resulted in greater plant N uptake relative to CP-CF treatments. A stable trend in NHI was observed across the treatments under irrigation, with an average of 70% of total aboveground N in the seed. The NHI for treatments under dryland conditions was less predictable, but tended to be higher with the EI and AP treatments. Under dryland conditions the average aboveground N in the seed was 62%, which was 8% less than for the irrigated treatments.

Seasonal Plant Biomass, Nitrogen, and Partitioning

The seasonal plant biomass and N dynamics presented here will focus on the CP and EI treatments of the irrigated environment. Large differences in seasonal biomass accumulation were observed from low (CP, **Figure 4a**) to the high (EI, **Figure 4b**) intensification treatments. At flowering (R1 stage), cumulative plant biomass relative to the final end-season value was lower (16%) for the EI treatment than the CP treatment (27%). A lower value means that a higher proportion of total plant biomass (more than 80%) for the EI treatment was accumulated during the most critical stages of the reproductive period. The EI treatment accumulated 60% more biomass by the end of the season than the CP treatment. This additional EI treatment biomass was primarily produced after the beginning of flowering (R1), with a stable rate of accumulation up until the end of the grain-filling period (**Figures 4a** and **4b**). This difference in total plant biomass and seasonal accumulation was the main factor governing yield differences between these two "input" scenarios, since the difference in HI between EI

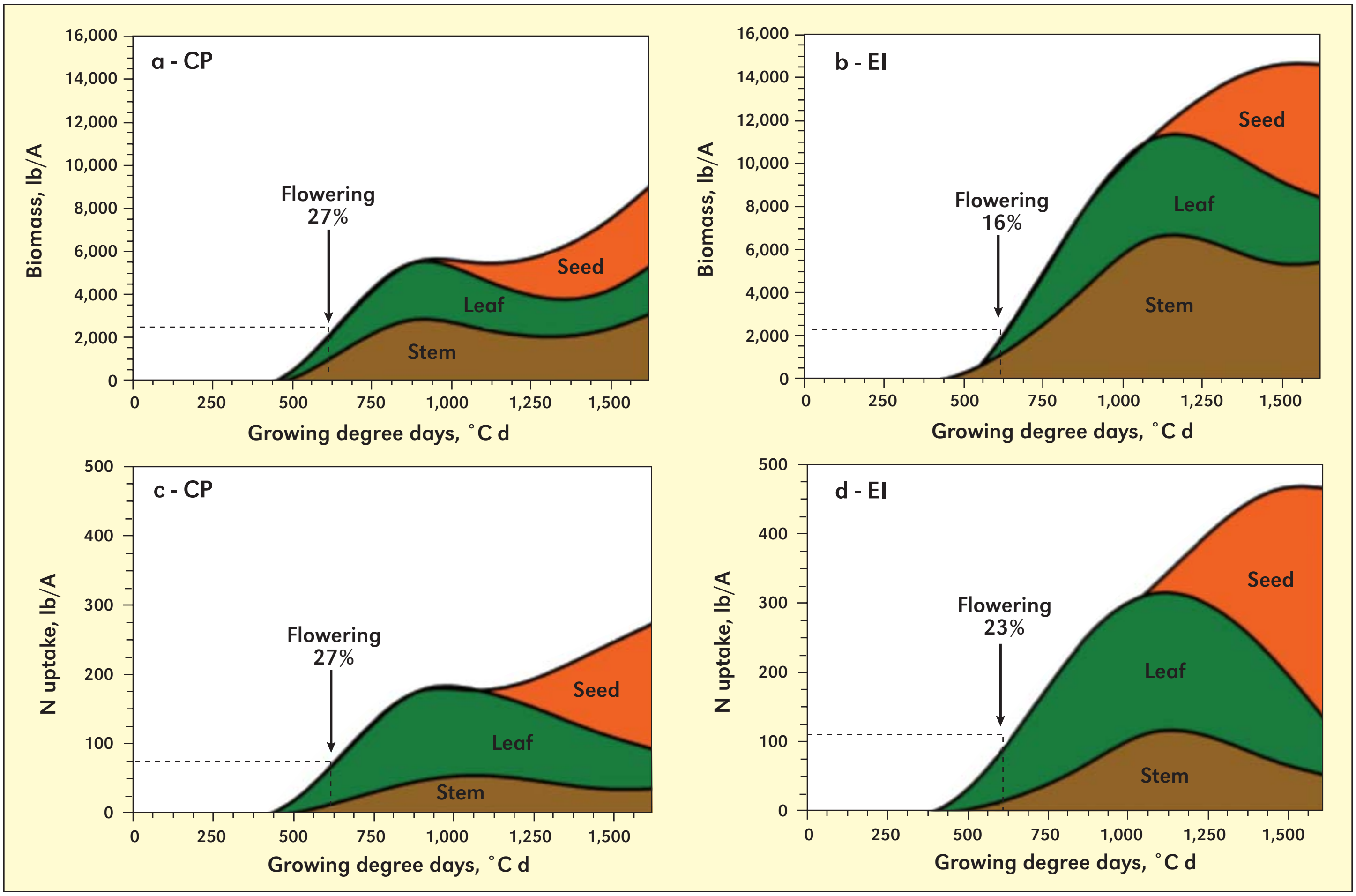


Figure 4. Soybean seasonal plant biomass and N uptake for common practice (CP) and ecological intensification (EI) by plant fractions in the irrigated scenario at Scandia, Kansas, average of 2014-2015 growing seasons.

and CP treatments was negligible.

Seasonal N uptake for the CP and EI treatments followed the same patterns as plant biomass accumulation (**Figures 4c** and **4d**). Greater plant N uptake—close to two-fold—was observed with the high-yielding EI treatment compared to CP. The lower N uptake with CP corresponded with lower yield compared to the EI treatment. Furthermore, the greater N uptake for EI was accompanied by a 5% improvement in seed N partitioning (NHI of 71% for EI vs. 66% for CP).

Summary

Intensifying productivity via utilization of improved fertilizer and crop management practices (i.e., narrower row spacing, higher seeding rate, and balanced nutrition) impacted plant biomass, N uptake, and the partitioning efficiency measured by seed HI and NHI components.

Nitrogen partitioning, or NHI, increased with the intensification of the farming system; meanwhile, seed HI remained unchanged under the high-yielding, irrigated environment. In this environment, balanced nutrition was a key factor in sustaining greater biomass and N uptake.

Early light interception, which was greater for EI than CP, was not translated into early biomass changes; however, a greater rate and duration of plant growth was documented during the late-reproductive period with better early canopy coverage and light interception, as was indicated by the ultimate 60% greater biomass with EI compared to CP.

Sustainable intensification of soybean production systems requires an integrated approach, which combines optimal nutrient and crop production practices that result in improved efficiency of the overall farming system.

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References

Cassman, K.G. 1999. Proc. Natl. Acad. Sci. 96:5952-5959.

Can Agronomic Phosphorus Recommendations for Potato be Environmentally Sustainable?

By Ester Zamuner, Jaume Lloveras, and Hernan Echeverría

A better understanding of the relationship between the agronomic and environmental optimum for soil test P can guide potato growers in Buenos Aires province towards improved P fertilizer management.

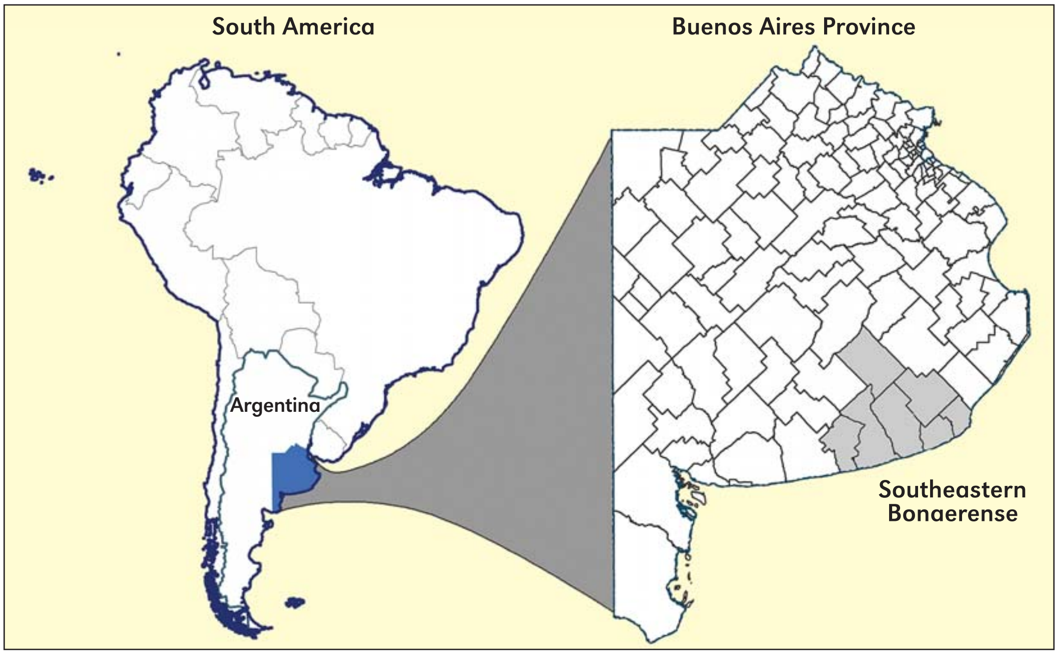


Figure 1. Shaded area shows the experimental area in the Southeastern Buenos Aires Province, Argentina.

The management of P is a critical component for potato production systems since the crop has a high P requirement but low P use efficiency, mostly because of its low root density (Fixen and Bruulsema, 2014; Rosen et al., 2014). In the southeastern Pampas region of Argentina (**Figure 1**) soils are commonly found to have low extractable P concentrations (less than 10 mg/kg) as determined by the Bray and Kurtz 1 (Bray-1 P) method. But in this region, potato crops typically respond to P fertilization even in soils with P availability that is considered high for other crops.

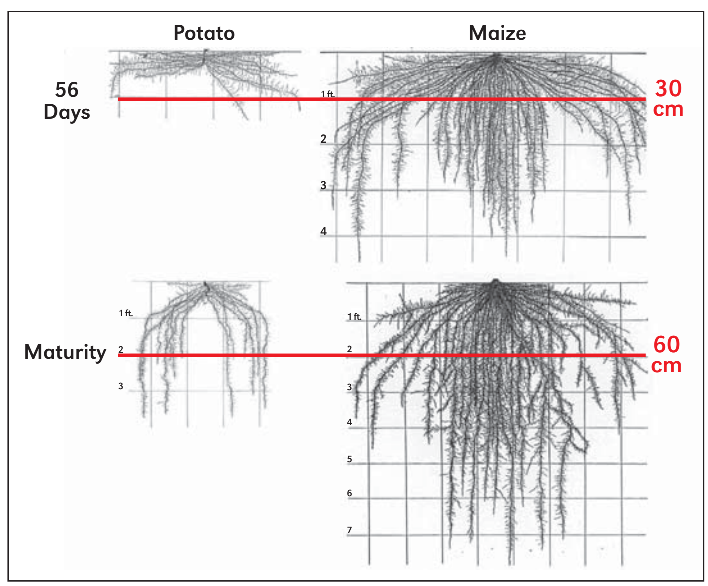
Since the cost of fertilization represents a low proportion of the final cost of production (approximately 8%) for this high value crop, producers often use larger amounts of P than necessary to reduce their risk of soil P insufficiency. If excessive P fertilizer is applied, the concentration of soil P can exceed the soil's retention capacity and the risk of P loss (via runoff or leaching) rises, especially during conditions of excess water. Excess P in streams, rivers, and lakes leads to eutrophication and can impact end-use quality and value (i.e., water supply, irrigation, recreation, etc.). The use of established thresholds for soil P availability can ensure high levels of crop productivity while minimizing environmental impact.

The definition of the agronomic critical P threshold is the soil P concentration beyond which no significant increase in yield will be expected with a further increase in fertilization.

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

In this study, data from 13 P fertilization trials conducted between 2005 and 2014 were used to calculate this threshold for the potato-producing area of southeastern Buenos Aires province. This region has an average annual temperature of 13.8°C and average rainfall during the crop growing season of 670 mm. Most of the soils are non-calcareous, with no evident limitations for agricultural use. Some of the chemical properties of the experimental sites are listed in **Table 1**.

In each trial, soil samples (0 to 20 cm depth) were collected before planting. Extractable P was determined by the Bray and Kurtz 1 method. In each field experiment, potato, cv. Innovator, was planted between mid-October and mid-November. Four to six P fertilizers rates were evaluated at each field trial, using triple superphosphate (20% P) as the P source (**Table 1**). In order to maintain an appropriate N supply, urea (46% N) was added to each plot using 120 kg N/ha at planting and 100 kg N/ha at hilling. Irrigation was applied and disease and



Potato versus maize root development at 56 days after planting and at maturity (Weaver, 1926). Reprinted with permission from Fixen and Bruulsema. 2014, p.128. © Springer.

Table 1. Some soil characteristics (0 to 20-cm depth) and average tuber yields for the six P rates evaluated at the thirteen field trials conducted at southeastern Buenos Aires province (Argentina) conducted between 2005 and 2014.

Field trial	Bray-1 P mg/kg	pH	Organic matter %	Potato yield with P rates[1], kg/ha 0	25	50	100	150	200
				---------- t/ha ----------					
1	19	6.2	5.2	49.1 c	55.5 bc	62.8 ab	69.7 a	-	-
2	27	6.0	4.2	36.6 a	39.3 a	39.1 a	42.2 a	-	-
3	33	6.1	5.2	44.6 a	46.6 a	44.2 a	45.9 a	-	-
4	15	5.8	5.2	30.6 b	41.1 a	42.0 a	47.8 a	-	-
5	14	5.8	5.2	54.1 c	59.2 b	67.2 ab	75.3 a	-	-
6	22	6.1	5.4	37.1 b	39.9 b	43.9 a	45.9 a	-	-
7	9	6.2	5.4	44.7 b	64.4 a	65.7 a	73.5 a	-	-
8	29	5.9	5.8	66.3 a	-	-	65.1 a	-	75.6 a
9	11	6.6	3.8	49.4 c	53.6 bc	64.0 b	67.5 ab	-	75.5 a
10	45	5.9	6.1	58.5 a	65.3 a	66.1 a	70.5 a	-	-
11	20	5.9	6.5	63.7 b	64.5 ab	70.8 ab	77.2 a	81.2 a	75.5 a
12	19	6.0	5.0	43.5 c	50.4 bc	54.2 ab	57.2 ab	60.7 ab	65.1 a
13	19	6.0	5.6	46.9 c	51.5 bc	55.0 bc	57.9 ab	65.4 a	62.9 ab

[1]For each field trial, values followed by the same letter are not significantly different ($p < 0.05$).

pest controls followed recommended local practices. Crops were harvested between mid-February and mid-March and the fresh yield was determined. Potato yields obtained from the field experiments were then used to estimate yield responses to P fertilization and expressed as relative yield (RY). The RY was calculated for each trial by dividing the mean yield of the unfertilized treatment by the mean yield of the fertilized treatment with the highest yield, and then multiplying the result by 100.

Potato yields ranged from 31 to 81 t/ha across the different trials and P rates (**Table 1**). Phosphorus fertilization produced significant yield increases in 9 of the 13 experiments. On average, the unfertilized plots yielded 22 t/ha less than those fertilized with the highest P rate.

Average RY for each trial were plotted against initial soil Bray-1 P (**Figure 2**). The P threshold required to identify soils with positive responses to P fertilization was 32 mg/kg. No significant yield increase was observed above this threshold (Zamuner et al., 2016).

Agronomic versus Environmental Thresholds

Soil tests that assess the potential impact of soil P on the amount of P delivered to water bodies are commonly referred to as "environmental" methods. One of these methods is based on the extraction of P using calcium chloride (P-$CaCl_2$). Pöthing et al. (2010) concluded that if the value of P-$CaCl_2$ is greater than 5 mg/kg—known as the environmental critical P level—there is a risk of P loss from the soil. Use of such an environmental threshold is not common in Argentina and its on-farm implementation would still require the need to conduct two separate soil tests: one to establish the need for fertilization (Bray-1 P), and another to assess the environmental risk (P-$CaCl_2$).

In order to establish a relationship between Bray-1 P and P-$CaCl_2$, 137 soil samples obtained from the 13 field trials were analyzed (**Table 1**). Using the regression equations, a critical environmental threshold range of 37 to 39 mg/kg Bray-1 P was correlated to 5 mg P/kg P-$CaCl_2$ (Zamuner et al., 2015; **Figure 3**). This critical range should be considered a preliminary result since there is a large scatter in the Bray-1 P data around the value of 5 mg P/kg P-$CaCl_2$. However, since this preliminary range of critical environmental P values is greater than the range of critical agronomic P values (**Figure 4**), it can be concluded that a conflict between the productivity and environmental sustainability goals is unlikely for this potato production system.

Bray-1 P values for surface soil samples taken from this region of the Pampas rarely exceed the environmental threshold of 37 to 39 mg/kg Bray-1 P, so it is quite safe to assume that there would be no general risk of P loss. However, we can use field trials 7, 8, and 12 to illustrate how Bray-1 P measurements can change during the potato-growing season in response to P fertilization, and raise concern depending on the site.

Generally, Bray-1 P values increase in immediate response to the application of P fertilizer, but then decrease due to the effect of soil chemical reactions and crop uptake (**Figure 5**). Soil in trial 7 had low initial Bray-1 P (9 mg/kg; **Table 1**) and application of the recommended rate of 100 kg P/ha did not raise Bray-1 P above the environmental limit at any point in the growth cycle. At trial 8, pre-plant Bray-1 P was relatively high at 29 mg/kg, but still lower than the agronomic critical P threshold. The recommended rate of 25 kg P/ha did not elevate Bray-1 P beyond the environmental critical P threshold during the growing season; however, application rates of 50 and 100

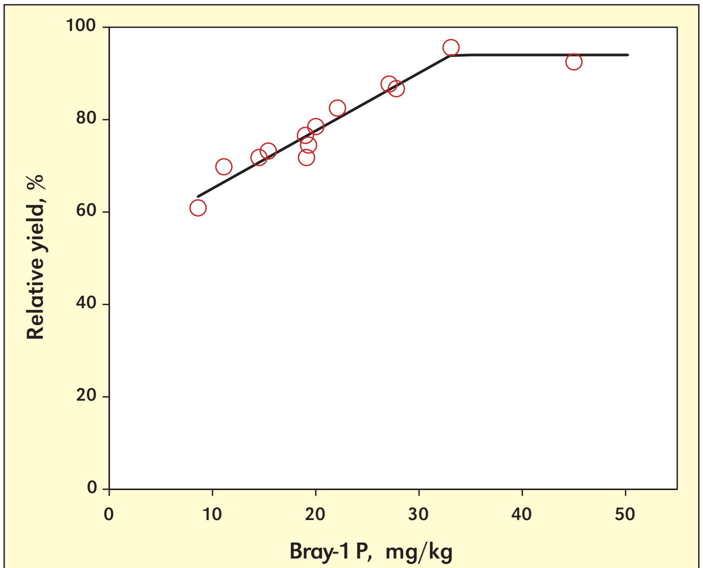


Figure 2. Relationship between extractable soil Bray-1 P and potato relative yield. RY = 1.25 (± 0.13)* P-Bray 1 + 52.6 (± 2.5) when RY < 92%, R^2 = 0.96 (Zamuner et al., 2016).

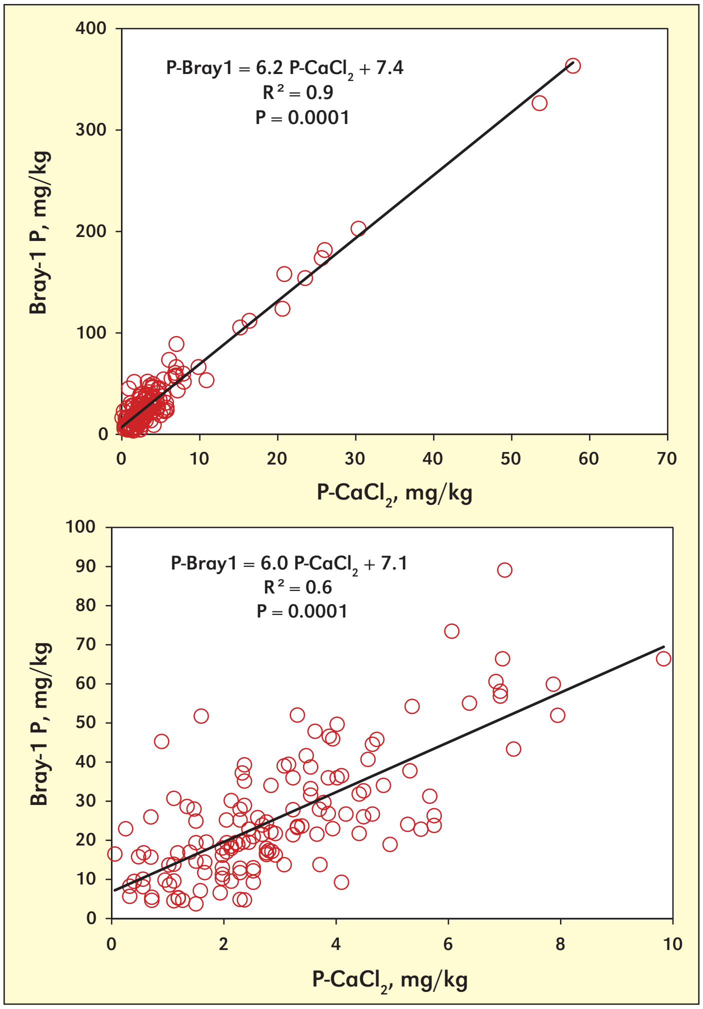


Figure 3. Relationship between soil P concentrations extracted with calcium chloride (P-$CaCl_2$) and Bray-1 P. The top figure shows the relationship for the whole range of soil P concentrations explored, and the bottom figure shows the relationship for the range of soil P concentrations around the environmental critical of 5 mg/kg of P-$CaCl_2$ suggested by Pöthig et al. (2010).

kg P/ha did raise Bray-1 P above the environmental threshold during the first 60 days after planting. Lastly, trial 12 had an initial Bray-1 P concentration of 19 mg/kg and recommended P rates in excess of 50 kg P/ha generated Bray-1-P values over the environmental threshold during the first two months after planting.

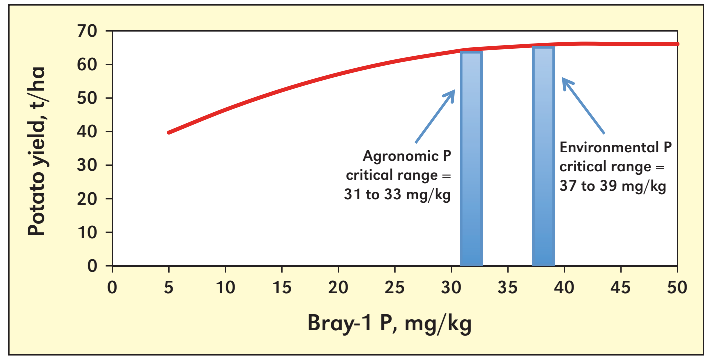


Figure 4. Relationship between extractable soil P as Bray-1 P and potato yield. Agronomic P critical range = P soil test range above which there is no significant crop response to P fertilization. Environmental P critical range = P soil test range below which there is no environmental P risk.

Summary

The results above highlight the importance of research that can accurately define critical soil test levels for cropping systems of concern. Irrigated potato production systems can be prone to conditions that increase the risk for environmental P loss; however, grower's can manage this risk by applying the concept of the critical P threshold. Fields with pre-plant Bray-1 P concentrations that are close to the critical environmental threshold should be managed in order to reduce the potential for leaching and runoff losses that can occur with excess irrigation water or rainfall, particularly on sloping surfaces and within the first 60 days after planting. BC

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References

Fixen, P.E. and T.W. Bruulsema. 2014. Am. J. Potato Res. 91:121-131.

Pöthig, R., H. Behrendt, D. Opitz, and G. Furrer. 2010. Environ. Sci. Pollut. Res. 17:497-504.

Rosen, C.J., K.A. Kelling, J.C. Stark, and G.A. Porter. 2014. Am. J. Potato Res. 91:145-160.

Weaver, J.E. 1926. Root Development of Field Crops. McGraw-Hill, New York.

Zamuner, E.C., J. Lloveras, and H.E. Echeverría. 2015. Ciencia del Suelo. 33:55-63.

Zamuner, E.C., J. Lloveras, and H.E. Echeverría. 2016. Agron. J. 108:1237-1245.

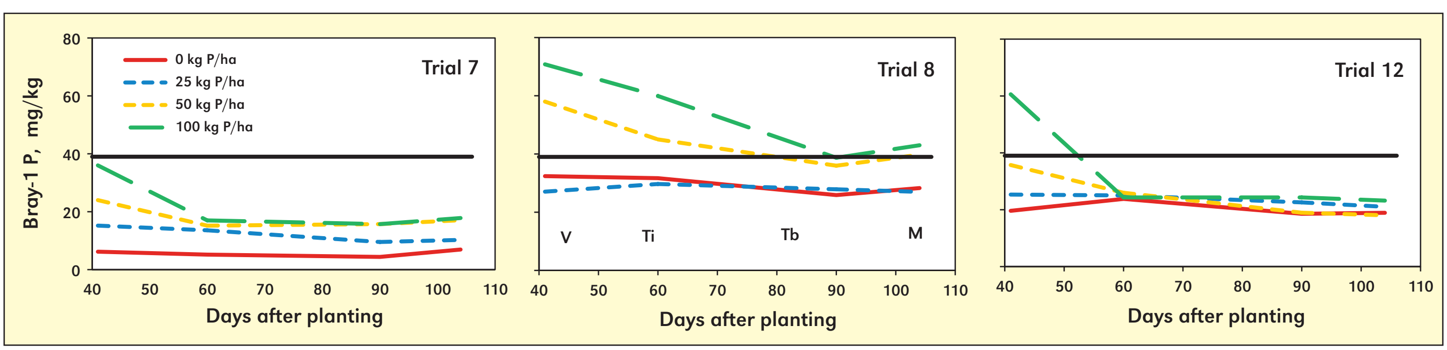

Figure 5. Extractable Bray-1 P in soil samples (0 to 20 cm) across two growing seasons for potato crops fertilized with 0, 25, 50, or 100 kg P/ha. Crop growth stages: V = vegetative growth; Ti = tuber initiation; Tb = tuber bulking; M = maturation. Horizontal black line corresponds to environmental P critical value.

Caravan vehicles at a date palm extension site.

Promoting Agricultural Production with Agricultural Caravans

By Mohamed A. Zain

The caravan has a long and vivid history in West Asia and North Africa. Historically used as more reliable method of establishing trade, their original routes successfully bridged difficult terrain and aided early economic development throughout the region.

Today, the concept of these original trade caravans is being applied as an effective agricultural extension tool. The goal is to provide a forum filled with agronomic specialists, and to provide farmers direct access to the expert advice they need to be successful.

As a touring event, the caravan can adapt to the specific issues that may be present at the site, and respond to the full range of challenges that farmers experience. Mobile workshops are held to educate farmers on the latest land preparation, planting, and crop care methods. The concept of 4R Nutrient Stewardship is interwoven into discussions on fertilizer product awareness, new technologies for soil analysis, fertilizer and water (irrigation) applications, and high productivity agriculture.

The date palm-farming community in Saudi Arabia recently benefited from an agricultural awareness caravan tour conducted late this past year with the collaboration of the Ministry of Environment, Water and Agriculture, and the Arab Fertilizer Association. The caravan provided advisory services to date palm farmers with the aim of seeking solutions to the problems being experienced in the field, and raising overall farm productivity.

The mobile showcase exhibit on devices needed to detect and eradicate the red palm weevil.

Comprised of five specially equipped vehicles, the caravan toured through the Al-Riyadh, Al-Ahsa, Qassim, and Madinah regions. Caravan vehicles were equipped with internet-enabled devices, audio-visual systems, and a mobile lab to analyze soil and water samples.

Caravan extension specialists discussing date palm agronomics with farmers in Saudi Arabia.

As part of the caravan's program, agricultural specialists and agricultural ministry officials visited many farms in each region and advised farmers on correct palm cultivation methods. For many of the farmers, this was their first introduction to the concept of 4R nutrient management. In addition to this recent caravan in Saudi Arabia, similar caravans have been successfully held in Morocco and Egypt to bring agronomic advice directly to farmers.

In addition to agriculture, these caravans offer medical and educational programs. This range of activities is designed to support the development goals of local communities, improve the daily life on the farm, and enhance the relationship between farmers and the agricultural industry that supports them. BC

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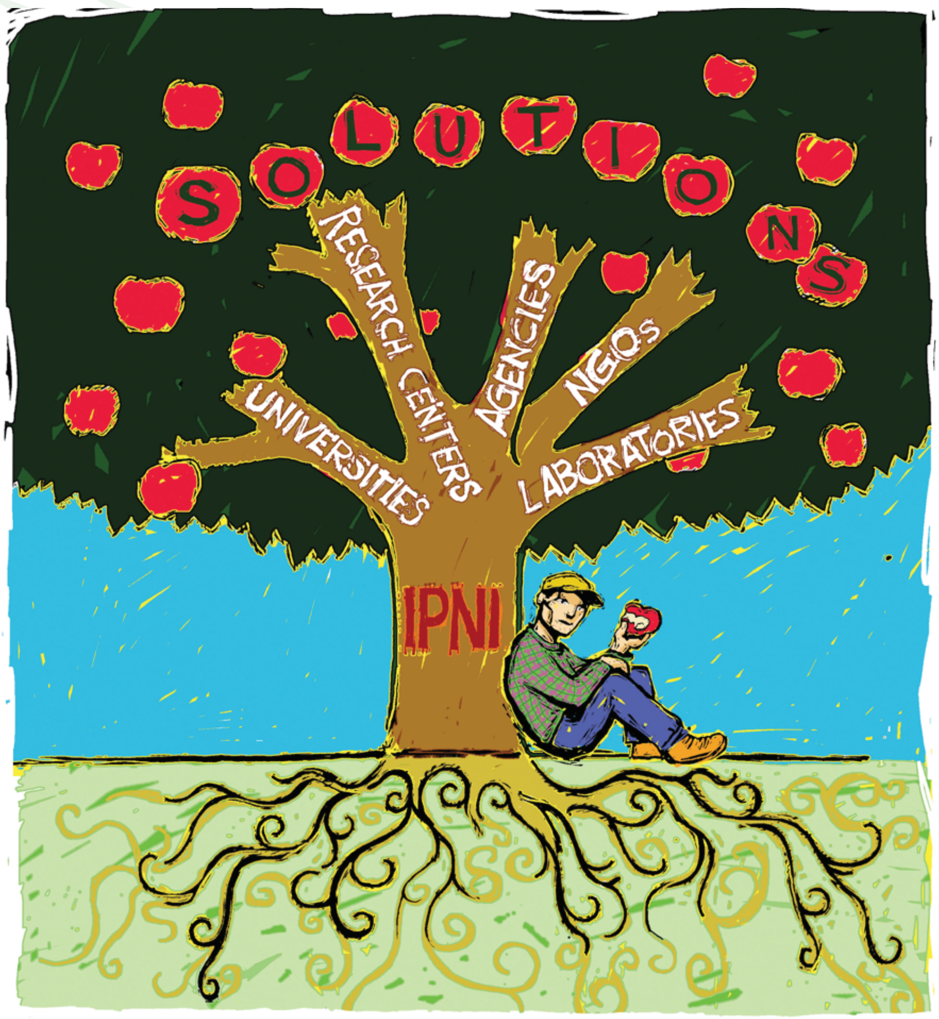

The technology of agronomy today is truly amazing, ranging from remarkable advances in genetics to tools for real-time cropping system monitoring and everything in-between. Equally amazing is the speed with which these technologies are advancing and the promised future acceleration resulting from research tools like the genome editing CRISPR/Cas9. It's a struggle for our scientific understanding of applications to keep up and offer essential guidance on how these technologies can form real solutions. More than ever in history, the effectiveness of agronomic science will be largely determined by its continuous linkage with the end-user and the dynamic technology surrounding that end-user.

It should not be surprising that at events today featuring the latest technologies, the greatest interest is not so much on hardware or anything that occupies physical space in a warehouse, retail store, or farm. It's on reliable, credible knowledge on how those technologies can best be put to use in adding value to businesses, whether the business is a farm or an entity supporting the farm. Relevant, applied science, viewed through the filter of local experience, is the source of much of that valued knowledge for converting technology into solutions.

A recent paper by Daniel Sarewitz (http://www.thenewatlantis.com/publications/saving-science) entitled "Saving Science" provided a sobering review of contemporary science in general, but makes several points highly relevant to the science of crop nutrition. A key message from Sarewitz is that science is most valued when it is closely linked to the people and places whose urgent problems need to be solved—who are in need of solutions. He argues that successful research institutions will "link research agendas to the quest for improved solutions—often technological ones—rather than to understanding for its own sake."

The focus of IPNI programs and our network of collaborators around the world is squarely on developing and applying science-based solutions to critical nutrient stewardship problems. Our staff position themselves to engage the fertilizer industry and its farmer customers, not just as an audience for delivery of solutions, but as collaborators in developing them. We keep our **roots in reality**.

Paul E. Fixen
IPNI Senior Vice President and Director of Research

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