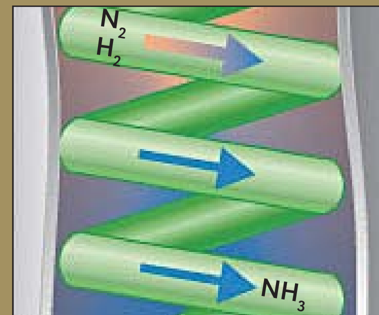
BETTER CROPS
WITH PLANT FOOD

A Publication of the International Plant Nutrition Institute (IPNI)
2014 Number 2

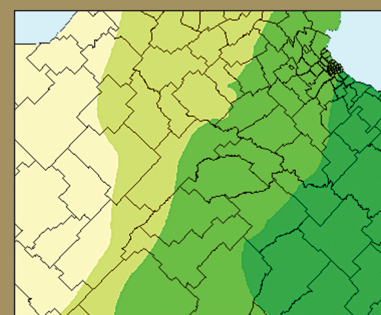
4R Specifics for Sunflower

In This Issue...

Reflecting on Haber Bosch



Integrating Soil Mineralization into the Nitrogen Diagnosis



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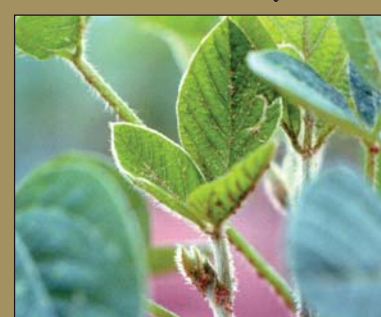

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Our cover: Sunflower field in Inner Mongolia, Northwest China
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Note to Readers: Articles which appear in this issue of *Better Crops with Plant Food* can be found at: >**www.ipni.net/bettercrops**<

International Stewardship Symposium in Saskatoon, Saskatchewan – July 15-16, 2014

The Canadian Fertilizer Institute (CFI) in partnership with The Fertilizer Institute (TFI), the International Fertilizer Industry Association (IFA), the International Plant Nutrition Institute (IPNI), and the University of Saskatchewan–through the Global Institute for Food Security and other academic partners–will be holding an International Stewardship Symposium entitled *Feeding Crops to Feed the World* on July 15-16, 2014 in Saskatoon, Saskatchewan.

The theme of this conference is focused on 4R Nutrient Stewardship's role in feeding the world, stewardship and greenhouse gas reduction, sustainability and how we measure our progress on a global scale. The conference will feature a seminar series entitled *"Utilizing 4R Nutrient Stewardship to Reduce Greenhouse Gas Emissions from the Application of Fertilizer and Other Crop Nutrients"* focusing on the role of 4R Nutrient Stewardship in reducing greenhouse gas emissions and improving the efficiency of crop production.

Examples of other planned sessions include international speakers on Extension & Smallholder Farms, Economics & Development, and Planetary Boundaries and Nutrient Use Efficiency.

Registration is now open at www.stewardshipsymposium.com where more information is available on the symposium speakers and the program. This website will be updated regularly, so please check back often. BC

The InfoAg Conference in St. Louis, Missouri – July 29-31, 2014

IPNI extends an invitation to all interested in the very latest precision agriculture information and technology to make plans to attend InfoAg this July.

Building on the especially strong momentum precision agriculture is gaining; the traditionally biennial event has been moved to annual schedule beginning this summer. InfoAg will be held July 29-31 at the Union Station Hotel in St. Louis, Missouri.

ZimmComm New Media


IPNI Photo

Since 1994, the InfoAg Conference has been the premier event for the discussion and advancement of precision agriculture. This event draws interest from domestic and international agriculture professionals and features a wide range of educational and networking opportunities for professionals interested in learning more about precision agriculture techniques.

The InfoAg 2014 Conference will focus on the application of precision technology and information management for a wide array of crops including cotton, soybeans, corn, and wheat. InfoAg is the perfect venue for you to grow and deepen your market relationships and place your company's brand in front of hundreds of qualified buyers ready to do business with your company.

The InfoAg Conference

Details on the program for InfoAg, registration, and conference contacts can be found at the website http://www.infoag.org

Additional links for The InfoAg Conference:

InfoAg Conference Newsletter: http://infoag.org/subscribe

InfoAg on Twitter: @infoag

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

Can Enhanced Efficiency Fertilizers Affect the Fate of Nitrogen in Loblolly Pine Plantations?

By Jay Raymond, Thomas Fox and Brian Strahm

Field experiments with isotopically labeled fertilizer N in managed loblolly pine (*Pinus taeda* L.) forests across the southern U.S. showed total soil and tree system N recovery ranged from 58 to 100% the first year after fertilization. The forest floor still contained 40 to 80% of the applied N at the end of the first year. Volatilization losses were less with enhanced efficiency N fertilizers compared to urea.

Forests in the United States provide a multitude of functions and services for society including clean water and air, wood and food products, wildlife habitat, and a variety of recreational opportunities. Forests are also providing an increasing supply of the raw materials needed to meet the demands of the emerging bioenergy industry. How forests are managed to meet these competing demands and interests is a fundamental question facing society in the 21st century (Sedjo, 1997).

Most forests in the U.S. are extensively managed with minimal silvicultural inputs. In these systems productivity is relatively low, with growth rates averaging around 2 to 3 m^3/ha/yr for southern pine—a rate insufficient to sustainably produce the raw materials required to support the competing interests of the existing forest products, the expanding bioenergy industries, and additional societal values. More intensively managed forest plantation systems, producing up to 10 to 12 m^3/ha/yr, will be required to sustainably supply the increasing demand for raw materials (Fox et al., 2007a). Theoretical models, empirical field trials, and operational experience indicate that growth rates in loblolly pine plantations exceeding 20 m^3/ha/yr with stand rotations of less than 15 years are biologically possible, financially attractive, and environmentally sustainable in the southern U.S. (Fox et al., 2007b)

Dramatic gains in growth can be obtained when intensively managed forest plantations are treated as agro-ecosystems, and site-specific silviculture prescriptions that ameliorate growth-limiting factors are implemented. Most forest plantations in the southern U.S. are established on relatively infertile soils with chronically low levels of available soil nutrients such as N and P that limit growth. Low nutrient availability restricts leaf area production, the main factor driving photosynthetic capacity and growth. Results from fertilization trials in loblolly pine stands indicate that most nutrient limitations can be easily and cost effectively ameliorated with fertilization. The growth response to a combination of 224 kg N/ha plus 60 kg P_2O_5/ha averages 3 m^3/ha/yr for an 8-year period (Albaugh et al., 1998). Fertilization is a common silvicultural treatment used to increase tree growth on over 400,000 ha of loblolly pine plantations annually.

The precise fate of applied fertilizer N incorporated into crop trees, and within the general forest system, is not well understood. Only a small proportion (10 to 25%) of fertilizer N applied to forest plantations is taken up by the tree crop. The remainder of the fertilizer N is either "tied up" in other ecosystem components (soils, competing vegetation, litter, etc.) or lost (gaseous losses, leaching). The low rate of N uptake by the crop trees decreases the returns from investments. A better understanding of the fate of applied N fertilizer in plantation forests is needed to improve economic returns from investment in fertilization and to reduce negative environmental impacts.

Abbreviations and Notes: N = nitrogen; P = phosphorus; NH_3 = ammonia; NBPT = N-(n-butyl) thiophosphoric triamide, MAP = monoammonium phosphate, PCU = polymer coated urea.

Loblolly pine plantation that is extensively managed (top) compared to a plantation that is intensively managed (bottom).

Comparison of Urea and Enhanced Efficiency N Fertilizers

Enhanced efficiency N fertilizers (EENFs) are often used in agronomy to increase fertilizer N uptake, but urea is almost exclusively used as the N source in forest fertilization. This research was initiated to compare the uptake efficiency and environmental fate of N from urea and EENFs applied to loblolly pine plantations in the southern U.S. Urea was compared with three different EENFs: NBPT (urease inhibitor) treated urea (NBPT); MAP-coated urea treated with NBPT (CUF), and polymer-coated urea (PCU).

It is often difficult to precisely determine the amount of N taken up from fertilizer in forests because a large proportion of the N in the tree is obtained from the native soil N pool. To accurately quantify the amount of N in the crop trees derived from the applied fertilizer N, fertilizer enriched with stable isotopes of N (^{15}N) can be utilized. This technique enables researchers to separate the N derived from soil from that obtained from the fertilizer. Stable isotopes have been used in agriculture and forestry research for several decades, but are usually confined to laboratory or smaller scale experiments due to the significant cost of producing ^{15}N labeled fertilizers. This study employed ^{15}N enriched fertilizers applied to large field plots in loblolly pine plantations to determine N losses through volatilization and N uptake in the trees. The four different ^{15}N enriched fertilizer N sources: (Urea, NBPT Treated Urea, MAP Coated Urea + NBPT; and Polymer Coated Urea) were applied at a rate of 224 kg N/ha to 100 m^2 circular plots mid rotation (approximately 10 to 12 years old) in loblolly pine plantations at 18 sites in the southern U.S. Six sites were installed in 2011 and 12 sites were installed in 2012. At the sites installed in 2011, the fertilizers were applied to separate plots at two different times (late winter and summer). In 2012, the fertilizers were applied during the late winter only. To better understand N losses through volatilization, a microcosm experiment was established adjacent to the plots installed during 2011, which eliminated root uptake so that gaseous N losses could be determined based on ^{15}N recovery in the microcosm through time. To assess fertilizer ^{15}N uptake by the crop trees during the growing season, foliage was collected every six weeks at the 2011 sites, and during the middle of the growing season for the 2012 sites. At the end of the first growing season after fertilization, a biomass harvest was conducted at all sites to determine the amount of applied ^{15}N present in the ecosystem using a mass balance calculation approach. The major components (crop tree, litter, understory and overstory competition, forest floor, mineral soil, etc.) at each site were collected and returned to the laboratory to determine N content (%) and ^{15}N (‰) for each sample using an IsoPrime 100 EA-Isotope Ratio Mass Spectrometer (IRMS). The ^{15}N that could not be accounted for in the mass balance for each plot was assumed to be lost from the system through NH_3 volatilization, leaching from the soil profile, or some other form of loss.

Preliminary Results

The preliminary results from one of the studies located at the Appomattox-Buckingham State Forest in the Piedmont of central Virginia are summarized. Recovery of applied ^{15}N from the microcosm experiment was used to determine NH_3 volatilization and N leaching from the soil profile. Greater ^{15}N recovery rates were observed from all EENFs compared to urea after both late winter and summer fertilizer applications (**Figure 1**). The ^{15}N recovery rates for the late winter fertilization ranged from 93 to 100% after Day 1 for the EENFs compared to 80% for Urea. After 15 days, the recovery rates

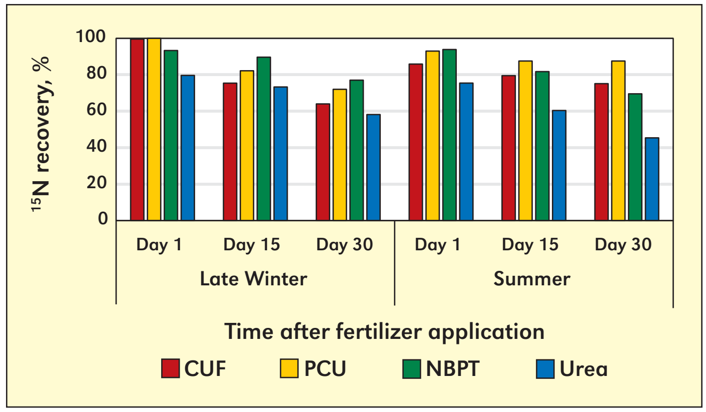


Figure 1. The percentage of ^{15}N enriched fertilizer recovered after 1, 15, and 30 days at a site in the Piedmont of central Virginia.

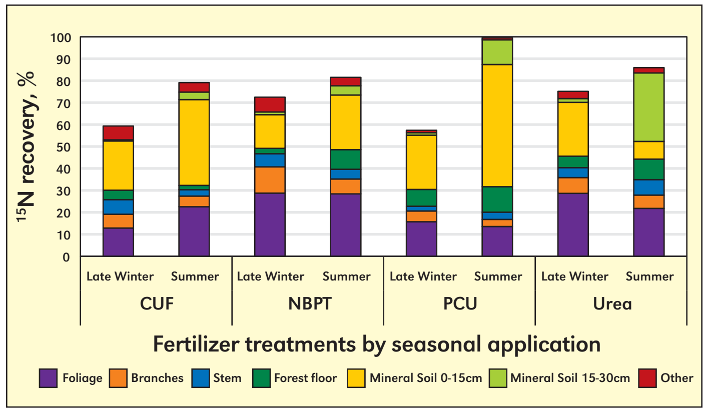
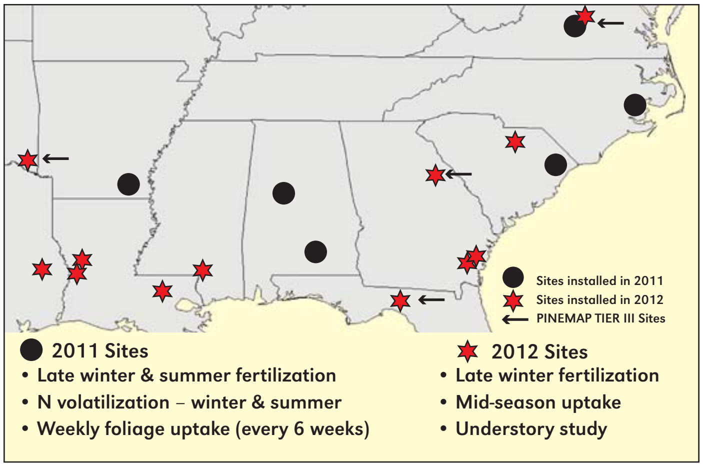


Figure 2. The percentage of ^{15}N enriched fertilizer recovered at the end of the first growing season after a spring and summer fertilization at a site in the Piedmont of central Virginia.

for the EENFs ranged from 75 to 90% whereas urea was 73%. After 30 days, the recovery rates for EENFs ranged from 64 to 77%, whereas urea was 59%. The ^{15}N recovery rates for the summer fertilization were slightly lower for Day 1 compared to late winter fertilization. The recovery rates for EENFs ranged from 85 to 94% after Day 1 whereas urea was 76%. After 15 days, the recovery for EENFs was 88 to 89% compared to urea, which was 60%. On Day 30, the EENFs recovery ranged from 70 to 88% and urea was 45%. These initial results indicate less N is being lost through NH_3 volatilization from EENFs when compared to urea, after both later winter and summer fertilization.

Total recovery following late winter fertilization ranged from 57 to 75% for all fertilizers (**Figure 2**). Summer fertilization recovery rates were slightly higher, ranging from 80 to 100%. The largest pool of ^{15}N in the loblolly pine was the foliage. Between 13 and 29% of the applied fertilizer N was in the foliage following both late winter and summer application. Total uptake in the crop trees including foliage, branches and bolewood ranged from a low of 20% in the PCU treatment after the late winter application to a high of 40% in the NBPT treatment after winter application. The majority of the ^{15}N was located in the top 15 cm of the mineral soil. The surface 15 cm of mineral soil contained between 15 and 25% of the fertilizer



Map of 15N site installations.

N applied in the late winter and 8 to 55% of the fertilizer N applied in the summer. In all the treatments, between 40 and 80% of the applied fertilizer N was still in the forest floor or the mineral soil one growing season after fertilization. This residual N may continue to be available for uptake by the crop trees in subsequent years.

Summary

The preliminary results from this research indicate that volatilization losses following N fertilization were less when EENFs were applied compared to urea. Differences in ecosystem N recovery and tree uptake were more variable. Between 20 and 40% of the applied fertilizer N was taken up by the crop trees during the first growing season. Overall, the majority of the applied N remained in the forest floor and the mineral soil. Total ecosystem recovery of applied N ranged from about 58 to almost 100%, with generally greater recovery following summer N applications compared to late winter applications. BC

Mr. Raymond, Dr. Fox, and Dr. Strahm are with the Department of Forest Resources and Environmental Conservation, Virginia Tech, Blacksburg, VA 24061; e-mail: trfox@vt.edu.

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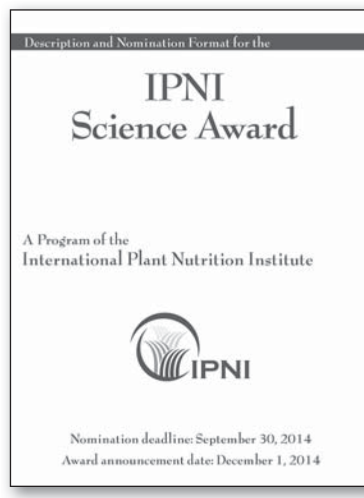
IPNI Science Award – Nominations Are Due September 30, 2014

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



Past Winners

2013: Not presented – minimum requirements for the award were not met.
2012: Mr. A.E. Johnston of Rothamsted Research.
2011: Dr. M.J. McLaughlin of the CSIRO.
2010: Dr. A.N. Sharpley of the University of Arkansas.
2009: Dr. J.K. Ladha of the International Rice Research Institute (IRRI).
2008: Dr. John Ryan of the International Center for Agricultural Research in Dry Areas (ICARDA).
2007: Dr. Milkha Singh Aulakh of Punjab Agricultural University (PAU), India.

The IPNI Science Award requires that a nomination form (no self-nominations) and supporting letters be received at IPNI Headquarters by September 30, 2014.

All details and nomination forms for the 2014 IPNI Science Award are available from the IPNI Awards website http://www.ipni.net/awards. BC

Proper Fertilization Helps Turfgrass Fulfill its Role in Protecting the Environment

By George Hochmuth

Based on requests for information about the science behind turfgrass BMPs, scientists in Florida reviewed the national literature to learn more about research on fertilization of turfgrass and potential problems with nutrient losses from turfgrass systems. One goal was to determine if there were scientific reports regarding a summer-restricted period against fertilization. The resulting paper "Urban Water Quality and Fertilizer Ordinances: Avoiding Unintended Consequences: A Review of the Scientific Literature" was published in Florida Extension literature (Hochmuth, G. et al. 2011), which was followed by a peer-reviewed article (Hochmuth, G. et al. 2012). This article summarizes some of the major findings of these papers along with a few of the major supporting publications.

Turfgrass is an important plant in the urban environment for maintaining aesthetic and economic value for residential, commercial, and recreational properties. In most areas of the country and especially in Florida, fertilizer is required to maintain healthy turfgrass. Warm-season types of turfgrass have been studied in Florida for their nutrient requirements and BMPs have been written for fertilization and irrigation. The BMPs are based on many years of research and are designed to provide for healthy turfgrass while protecting local water bodies from nutrient pollution due to lost fertilizer. Even though BMPs have been written and have been recommended statewide, there are some counties and municipalities in Florida that have opted to enact more strict local ordinances including prohibitions on fertilization of turfgrass in the summer months from June 1 through September 30. Florida is not the only state to have statewide or local guidelines for fertilizer use on turfgrass, but there are differing approaches among states and localities.

Eutrophication of our inland and coastal water bodies is a real concern and nutrient enrichment is associated with human activities. Point (e.g., waste water treatment) and nonpoint (agriculture and urban nutrient sources) can contribute N and P to water bodies through leaching and runoff. These nutrients may contribute to the degradation of the designated use for a water body. Total Maximum Daily Loads would be determined for the impaired water body and a Basin Management Action Plan would be employed to return the water body to it desired water quality level. Clearly this process would be expensive and time-consuming. Managing nutrient loss at the source would be a preferred approach and that is the intention of BMPs.

In residential areas there are numerous sources of nutrients including atmospheric deposition, pet waste, tree and plant leaf litter, and fertilizers. This review included research for all of these nutrient sources focusing on urban fertilization. Nitrogen, P and K fertilizers are commonly applied to lawns to achieve a desired level of plant growth and aesthetic value. Studies in Florida have documented the presence of fertilizer-derived nutrients in water bodies (Jones et al., 1996; Tampa Bay Estuary Program, 2008). While these studies show fertilizer nutrients are being found in urban water bodies, they do not conclude whether the nutrients were lost predominantly from landscapes fertilized properly according to BMPs or from improperly fertilized landscapes.

Abbreviations and Notes: N = nitrogen; P = phosphorus; K = potassium; BMPs = best management practices; ppm = parts per million.

Research demonstrates that appropriate fertilization is a major factor to maintaining healthy turfgrass that is able to efficiently take up nutrients and reduce nutrient loss from residential landscapes.

Beard and Green (1994) grouped turfgrass into *functional* (e.g., preventing erosion, preventing weeds), *recreational* (sports fields), and *aesthetic* (beauty and value-added homes and properties) functions. Healthy turfgrass can be described as turfgrass that maintains complete coverage of the soil and adds aesthetic beauty and value for the home site. In our scientific review we asked the question "does healthy turfgrass play a role in preventing nutrient loss from the urban environment?"

Numerous research studies in several states find that healthy turfgrass can efficiently take up nutrients and reduce nutrient loss from the landscape. Published books (Beard and Kenna, 2008; Nett et al., 2008) have summarized the research literature on turfgrass systems and their care, with attention to environmental impacts. Research shows that fertilizer-derived nutrients can be lost from the urban landscape under certain circumstances. For example, runoff losses were most likely when fertilizer is applied just before or during heavy rainfall

(Soldat and Petrovic, 2008), when fertilizer was applied before the turf root system is established (Erickson et al., 2010; Trenholm et al., 2011), or when fertilizer was applied in excess of research-based recommendations (Trenholm et al., 2011). In a study in Minnesota with Kentucky bluegrass, zero, low, and high P (and a zero control) fertilization programs were imposed during the year (Bierman et al., 2010). The researchers measured runoff volume and P loads moving off the research site plots. Where N and K fertilizers were supplied (better turfgrass growth), P in the runoff increased as the P rate increased. Phosphorus runoff from the unfertilized plots (no N and K and lower plant growth) was greater than from fertilized turf. The researchers attributed the increased P runoff to poorer growth of the turfgrass in the unfertilized plots. Phosphorus runoff was greater when P was applied in the fall, when plant growth slows and plants entered dormancy. These researchers concluded that P should not be applied in the fall or when soils already are high in P content, and that P runoff was reduced with healthy, fertilized (N and K) turfgrass.

In a 6-year study in Wisconsin, Kussow (2008) evaluated management practices that affect N and P losses from upper Midwest U.S. lawns. Annual nitrate-N leachate concentrations were typically between 2 and 4 ppm and the quantity of N leached was about 3 lb/A, which was intermediate between losses from agricultural and natural areas in the upper Midwest. The most important factor for increasing runoff loss of N and P was runoff depth. Next in importance was failure to fertilize for a healthy lawn.

Leached N averaged 0.23% of the total N applied over two years for Kentucky bluegrass (Miltner et al., 1996). Total recovery of N was 64 and 81% for Spring and Fall, respectively, pointing to potential gaseous losses of N making up the difference. Research showed that the active growth period is the time when the grasses have the greatest ability to take up nutrients, due to larger, denser, and more actively growing root and shoot systems.

These studies and others show that maintaining healthy turfgrass with appropriate fertilization is a major factor in reducing nutrient loss from residential landscapes. The research also points to possible negative unintended consequences for not following appropriate fertilization practices in residential lawns.

The authors reviewed the status of statewide and local regulations for fertilization practices in the U.S. For example, Minnesota had the first statewide rule for P fertilization in urban environments. Other states with rules include Michigan, Maryland, Wisconsin, and New Jersey. The rules in these states, unlike Florida, do not ban fertilization in the period of active turfgrass growth. Rather, they typically control fertilizer application through the use of BMPs, including the use of a soil test to predict P needs, the use of set-backs (buffers) from water bodies, advice on keeping fertilizer off impermeable surfaces, controls on total amounts of fertilizer per application and for the season, bans on fertilization in the winter when the ground is frozen or when the turfgrass is not actively growing, and allowing fertilization of newly planted turf seeds or sod. The ordinances in other states are therefore much like the Florida Department of Environmental Protection Green Industries BMPs and the state model ordinance (FDEP, 2008).

From our literature review and analysis, the following conclusions can be made:

- Coastal and urban eutrophication is a problem and is, at least in part, related to many urban land-based activities. Sources of nutrients involved with eutrophication are numerous and the interactions with harmful algal blooms are complex.
- Based on an analysis of national research, turfgrass has a large capacity for nutrient absorption. Unfertilized turfgrass will lead to increased runoff and nutrient losses as turfgrass health and density decline over time due to insufficient nutrient supply.
- BMPs for fertilization have been shown to be effective in reducing pollution of water bodies.
- Developing nutrient BMPs involves an iterative process based on science and must be sustained to develop continually advancing knowledge.
- The BMP solution avoids the "one-size-fits-all" approach because BMPs, by definition, provide for adjustments in the practices depending on local conditions and science-based recommendations.
- All published scientific research should be part of a comprehensive and complete discussion of approaches to reduce urban nutrient losses. All stakeholders should actively engage in this process.
- Research publications point to the importance of a continued education effort to inform homeowners about how their landscape practices impact water quality. Continuing the effort to educate the public about the BMPs, as determined by scientific research, is of the utmost importance. BC

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The Historical Development and Significance of the Haber Bosch Process

By David E. Kissel

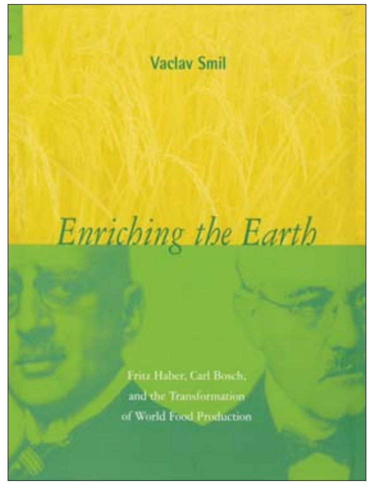
A review of key scientific discoveries in the mid 1800s on the role of N in crop production, and the later research in the early 20th century of scientists Fritz Haber and Carl Bosch that made N fertilizer production possible. Dr. Kissel draws from several sources for this historical assessment that links N supply with social change and security—especially from the book by Vaclav Smil entitled "Enriching the Earth" as well as "The Alchemy of Air" by Thomas Hager.

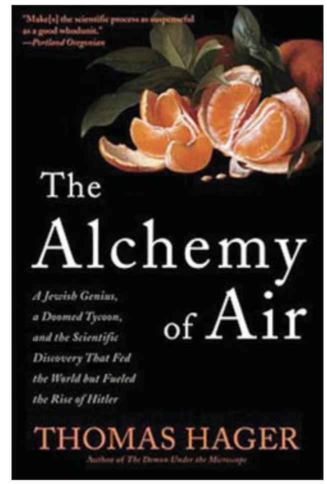
Today we in agriculture take for granted the importance of the production and ready availability of N fertilizer. But around 175 years ago, a group of scientists in Europe were involved in a scientific debate over how important ammonium and nitrate forms of N were for the growth of plants, and whether N fertilizers were needed at all. By 1836, the French chemist Jean-Baptiste Boussingault had summarized field experiments on manuring, crop rotation, and sources of N. He concluded that N was a major component of plants. An important question in 1840 was whether plants could get all of the N they needed from the soil and from the air. The great German chemist Justus von Liebig had concluded that soil and atmospheric ammonia supplied enough N for the needs of crops, but this conclusion was wrong. Scientists at the time who found the right answer to these questions were John Bennet Lawes and Joseph Henry Gilbert, who showed clearly at Rothamsted, England that addition of N fertilizers greatly increased yields of wheat. Why the great scientific interest in N during the 1800s? Besides the scientific curiosity to understand plant growth and plant nutritional needs, there was also the need to ensure food supplies for an expanding population.

In his book, Smil describes the doubling of wheat yields in England from 1750 to 1850, which he concluded was due to crop rotations that included more legumes, which in turn supplied more N to the following wheat crop. He noted that during the 500 years prior to 1740, legume use in the county of Norfolk, England was relatively constant at 13% of cropped land area whereas by 1836 it had doubled to 27%. Smil quoted from historian G.P.H. Chorley of the University College in London, who wrote about the importance of more legume use to industrialization during this period. Chorley's article, published in the journal Economic History in 1981 was titled "The Agricultural Revolution in Northern Europe 1752 to 1880: Nitrogen, Legumes, and Crop Productivity." Chorley concluded "*…there was one big change of overriding importance; legume crops and the consequent increase in the N supply. It is not fanciful to suggest that this neglected innovation was of comparable significance to steam power in the economic development of Europe in the period of industrialization.*" Smil wrote that Chorley did not exaggerate; he stated "*Industrialization would not have been possible without population growth. A higher N supply allowed not only more people per unit of arable land, but also for the slow but steady improvement of average diets.*"

Less than 50 years after the questions about N were settled by Lawes and Gilbert there were new questions and controversies over how the growing population of the industrialized

Abbreviations and Notes: N = nitrogen; M = million.





nations were going to feed themselves in the coming 20th century. At the end of the 1800s, Great Britain was importing much of its wheat. In an 1898 speech widely quoted in the popular press, William Crooks, the incoming president of the British Association for the Advancement of Science, made a case that "Industrialized Nations" must find a solution to the coming food shortage. He called for chemistry research to find a solution; hopefully, a scientific breakthrough that would allow the manufacture of N fertilizers.

The solution was to come first from the young German Physical Chemist Fritz Haber. Haber graduated in 1891 with a doctorate in chemistry. While employed by the University in Karlsruhe, Germany, Haber wrote many papers including one in 1905 in which he concluded that the chemical reaction of N and hydrogen gases to produce ammonia was not feasible, largely because the yields of ammonia in his experiments were too small. But another chemist, Walter Nernst, challenged Haber's work as incorrect. The public criticism drove Haber, with financial support from BASF, to restart the work on ammonia synthesis in order to clear his name. By March 1909 Haber and his colleagues, through much trial and error, had found the right combination of high temperature (500°C) and pressure (100 atmospheres) and just the right catalyst to show that the reaction could be successful. In July 1909, BASF assigned Carl Bosch to lead the team to develop commercial scale production.

Industrialization was not easy. Ammonia production was to be a continuous flow process at the extreme temperatures and pressures defined by Haber's work. Chemical production prior to this time had been done in batches, unlike what was being proposed. This meant that almost all of the machinery had to be invented for these extreme conditions, including flow gauges, pressure gauges, etc. that could withstand these

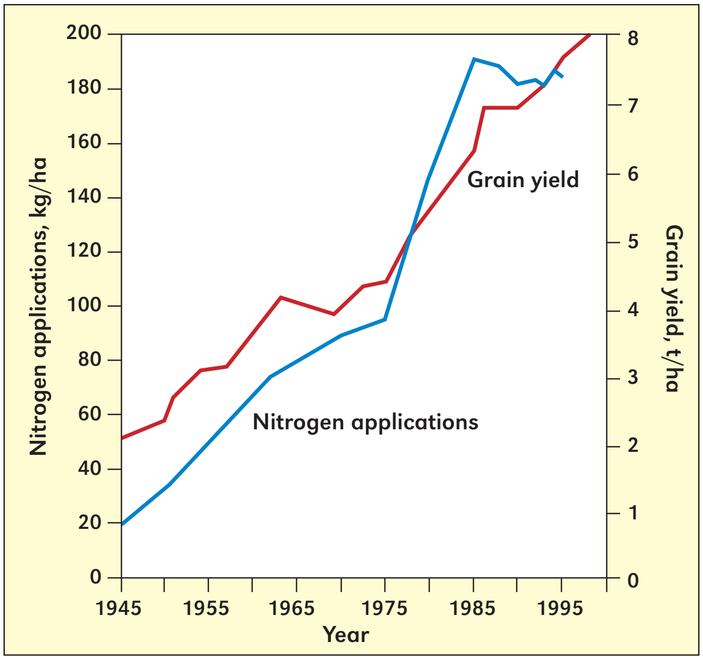


Figure 1. Nitrogen applications and yields of English winter wheat, 1945-1998. Source: Smil, 2001.

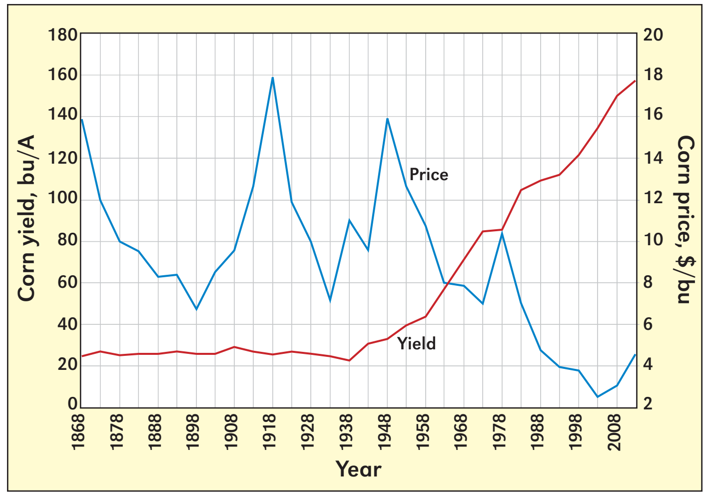


Figure 2. U.S. corn yields and price of corn (per bushel) normalized to the 2010-dollar value. Source: USDA ERS.

extreme conditions. Haber's lab-scale machine that produced 115 g of ammonia per hour was first duplicated by Bosch in the form of a 8 m tall industrial reactor at Oppau, Germany that produced 90 kg of ammonia per hour and the plant began full production in early 1914.

Shortly thereafter, WWI began and the plant soon installed the capability to produce nitric acid from ammonia, which greatly facilitated the manufacture of explosives for the war effort. According to both Smil and Hager, the invention of ammonia synthesis for agriculture greatly lengthened WWI because it could readily be used to make explosives. After the war, the German government at first attempted to keep secret the process for making ammonia, but in negotiations at Versailles to discuss reparations for WWI, Carl Bosch (a member of the negotiating team from Germany) offered to the French government the technical details to build a Haber-Bosch plant. By the early 1920s, the French were producing ammonia, and the British and the Americans soon followed with their own plants.

Two Nobel Prizes were awarded for this work, the first to Fritz Haber, presented in 1920 for his laboratory research describing the conditions needed to form ammonia from N and hydrogen gases. The second, given in 1932, was shared by Bosch and Frederick Bergius for "their services in originating and developing chemical high-pressure methods."

Today's modern ammonia plant is large, often producing over 1,000 tons per day. It takes about 0.65 tons of natural gas to make 1 ton of ammonia. The overall reaction is highly efficient, in part because about 40% of the hydrogen comes from water in the overall reaction. The N of course is from the air.

Haber Bosch has greatly increased yields of food and feed grain crops. Smil presented the changes in yields of wheat in England from 1945, when they were about 2 t/ha (30 bu/A), to 1998 when wheat yields were over 8 t/ha (120 bu/A) (**Figure 1**). The gradual increase in yields over this time were in parallel with the increase in N fertilizer application from about 20 lb N/A in 1945 to about 160 lb N/A in 1998. Corn grain in the U.S. is a similar story. Average yields of corn in the U.S. from 1868 until the present time are shown in **Figure 2**. Grain yield of about 25 bu/A changed little over the 70-year period from 1868 to 1938. After that time yields began to increase slowly, but then increased at a faster rate from about 1960 until the present time. No doubt the introduction of hybrid corn in the 1930s had a significant role. But the big factor, as with wheat production in England was N fertilizer use. Average yields increased at a modest and continuous rate from the early 40s until 1960, as did N fertilizer use. Nitrogen fertilizer use increased at a faster rate starting around 1960 and so did corn yields.

As described by Smil, a big change in ammonia manufacturing plants began to take place in the 1960s. The energy used to make ammonia in the new ammonia plants in 1970 was only 65% of what it had been 15 years earlier and less than half of pre-World War II plants. This allowed exceptionally low retail prices for ammonia at that time, for example in 1969 it was possible to purchase anhydrous ammonia for $0.04/lb of N. With low prices for N fertilizer and a relatively good price for corn, yields increased continuously over the next 30 years. By 2010 average yields were nearly 160 bu/A, which is more than a six-fold increase in yield in a period of 70 years. **Figure 2** also compares corn yield with the price of corn normalized to the 2010-dollar value. The low point on the graph around 2003 was around US$2.50/bu. The market price of corn has been trending downward from 1948 until 2005 with only one significant price increase around 1978. A similar price drop over this time also occurred for wheat and rice. Of course the effect of greatly increased N supply, the efficiencies of production due to N fertilizer, and all the other factors of production (plant breeding, pest control, mechanization, irrigation, and other plant nutrients) have all made the higher yields and increased efficiencies of production possible. The net result of all these improvements is a reduced price, which has had a big effect throughout the economy. For example in 1930 nearly 25% of U.S. family income was spent on food, but this percentage has dropped over the intervening 75 years to less than 10% today, which allows a higher standard of living.

In some respects N has become overly abundant. Fertilizer manufacture each year is 100 M tons, modern legumes like soybeans and alfalfa contribute another 40 M, and burning of fossil fuels an additional 20 M. This total of 160 M tons is about 55 to 60% of all N fixed each year. In other words humans have more than doubled the amount of N fixation in the past 100 years. And, much of this fixed N is concentrated on our best agricultural land in an environment where N may be lost by nitrate leaching, some of which may reach the marine environment and cause eutrophication. Ammonia volatilization from fertilizers and animal manures may also cause eutrophication and soil acidification. Finally some N may be lost as nitrous oxide by denitrification and nitrification; and nitrous oxide is a strong greenhouse gas.

But we cannot do without N fertilizer. The central challenge is to apply the correct rate of N and in the correct way and at the right time for the crop being grown. This means doing a better job of quantifying some components of the N cycle, perhaps the most important is quantifying the amount of N that becomes available from soil humus and decomposing crop residues in soils because these processes are so complex due to their dependence on environmental conditions. Perhaps better solutions will come from the integration of computer technology, weather data and soil and plant analysis. These challenges should be no greater than those facing Haber and Bosch 100 years ago. BC

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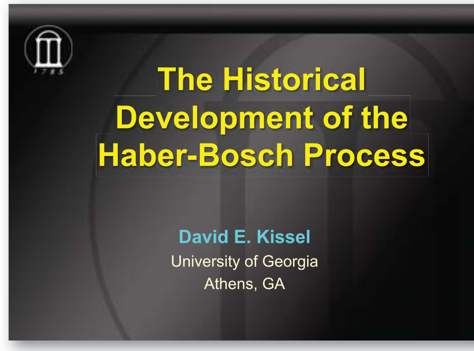
The article is a summary of the 2011 Distinguished Leo Walsh Lecture presented by Dr. David E. Kissel at the annual meetings of the Soil Science Society of America in San Antonio, Texas. The recorded lecture may be found at ACSESS Digital Library (2013).



A complete version of Dr. Kissel's presentation can also be obtained at http://www.ipni.net/article/IPNI-3359

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Examples of N response taken from the U.S. spanning the mid 1930s to mid 1950s. Better Crops with Plant Food Cover featured in March 1930.

Can a Soil Mineralization Test Improve Wheat and Corn Nitrogen Diagnosis?

By Nahuel Reussi Calvo, Hector E. Echeverría, Hernan Sainz Rozas, Angel Berardo, and Natalia Diovisalvi

A network of field studies determined that the traditional method for predicting soil N availability ...a pre-plant nitrate test ... can be combined with an indicator of soil N mineralization capacity to significantly improve the diagnosis for soil N availability for both wheat and corn.

The process of mineralization is a major source of available N for crops, particularly in soils with high OM content. Mineralization usually satisfies 30% and 60% of the N demand of wheat and corn grown in the southern region of Buenos Aires Province. However, soil N mineralization potential is site-specific. A simple and reliable way to estimate this potential in the region is the laboratory soil test known as *Nan*, which stands for *anaerobically incubated N*. This technique consists of measuring NH_4^+-N released during a 7 day, 40°C anaerobic incubation of surface soil (0 to 20 cm sample depth). The Nan test is closely correlated to potentially mineralizable N determined by long-term aerobic incubations (Soon et al., 2007), and it is sensitive to changes in management practices and tillage systems (Genovese et al., 2009). Moreover, the short period of time required to perform the Nan test represents an advantage over other methodologies that estimate N mineralization, which makes it useful as a routine method in soil testing laboratories.

In a soil survey in the Buenos Aires Province, Reussi Calvo et al. (2011) determined values of Nan ranging from 25 to 115 mg/kg. These values varied with location and tended to decrease from east to west (**Figure 1**). This change in Nan is evidence of different soil N mineralization potential within the area that should be considered when adjusting the rate of N application (Sainz Rozas et al., 2008; Reussi Calvo et al., 2013a). This particular pattern of N mineralization potential may reflect agricultural history, management practices, and climatic conditions (Genovese et al., 2009).

Response to N (on left) in an environment with low soil N mineralization as determined by the Nan diagnostic test.

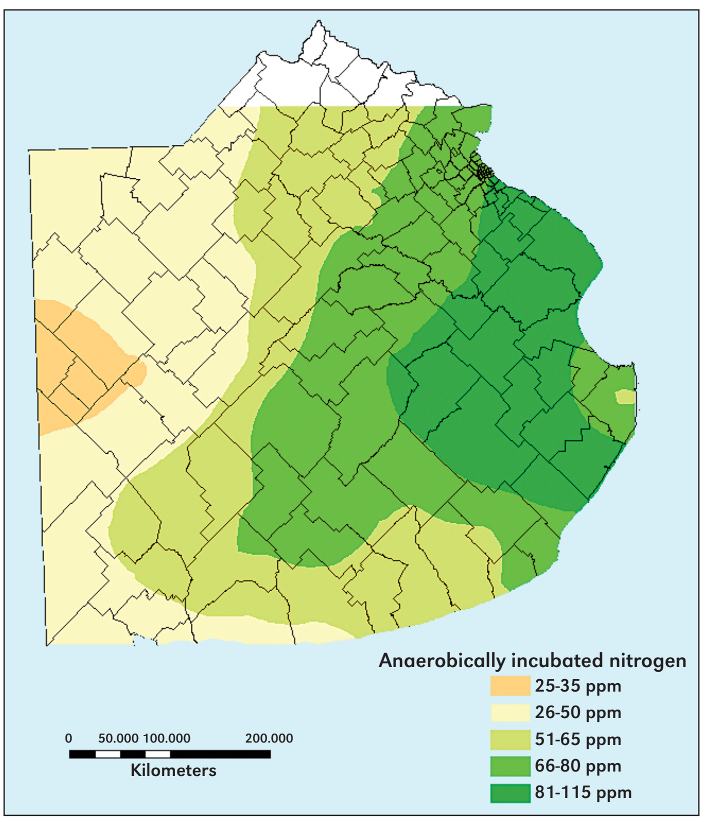

Figure 1. Average levels of anaerobically incubated N (Nan) in the surface layer (0 to 20 cm) of soil (3,240 samples) in the Buenos Aires Province, Argentina.

Today, the most widely used N diagnostic method for wheat and corn in Argentina is a NO_3^--N soil test of top 60 cm of the soil profile taken at planting time (Sainz Rozas et al, 2008; Barbieri et al, 2009). Different thresholds for N availability (soil + fertilizer) have been proposed, which vary by region, tillage system, and yield goal (Barbieri et al., 2009). However, this simplified model does not consider the direct contribution of soil N mineralization. Only 38 to 54% of the variation in crop yield is explained by NO_3^--N (0 to 60 cm) availability at planting time (Sainz Rozas et al, 2008; Barbieri et al., 2009).

Nan Experiments in Wheat

The contribution of Nan to N fertilization diagnose in wheat (**Figure 2**) was evaluated in southern Buenos Aires (Balcarce region) for a 5 year period at 28 sites. Soil OM content varied from 4.4 to 6.8 %, while Nan varied from 34 to 94 mg/kg and the availability of NO_3^--N varied between 39 and 130 kg N/ha. These values are strong indicators of a significant difference in soil N mineralization potential (Reussi Calvo et al., 2013a).

Only 24% of the yield variability in the control plots (CY) was explained by the soil NO_3^--N test (**Table 1**), which high-

Abbreviations and notes: N = nitrogen; NH_4^+ = ammonium; NO_3^- = nitrate; OM = organic matter; ppm = parts per million; RY = relative yield.

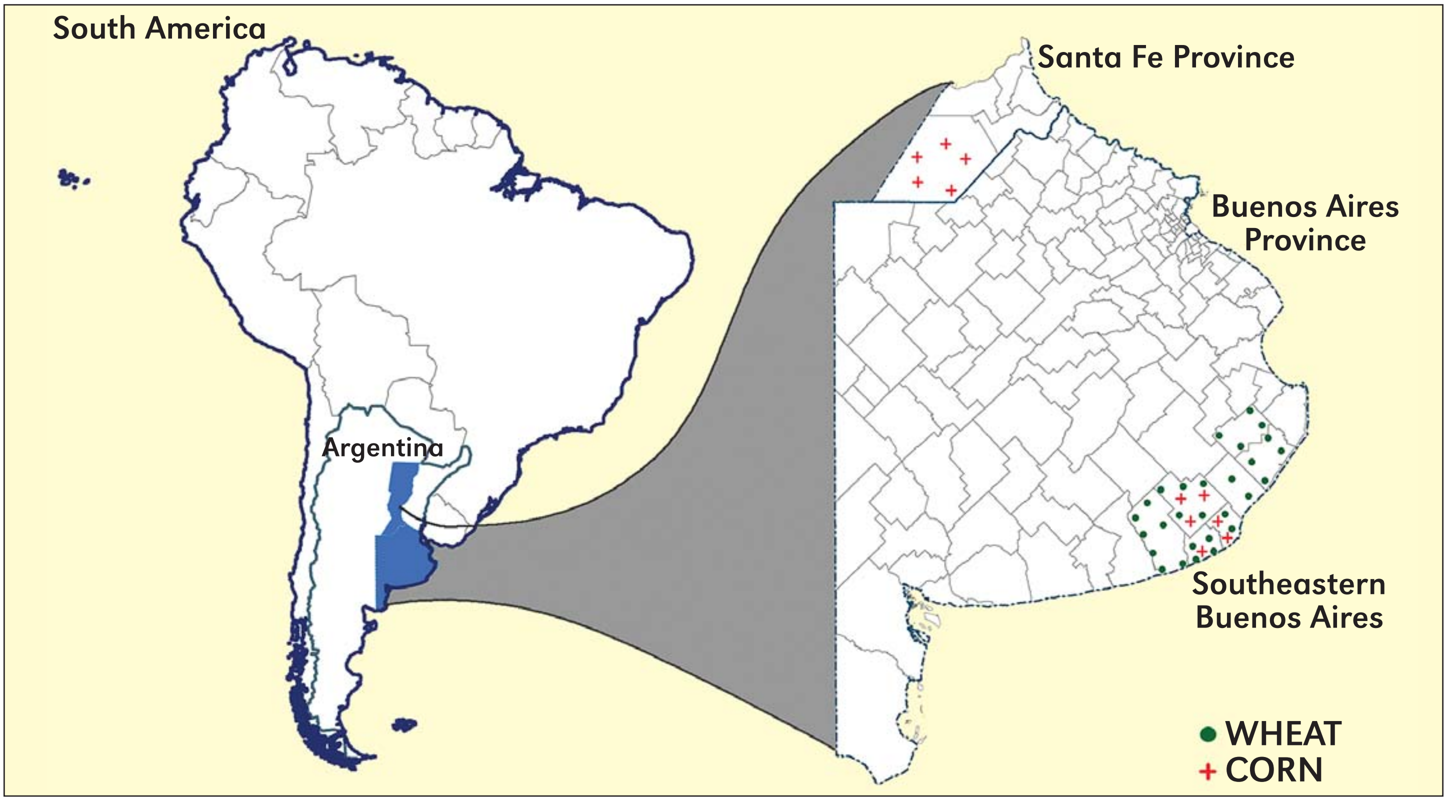

Figure 2. Location of experiments for wheat and corn in Santa Fe and Buenos Airies, Argentina.

lights the limitations of using this single variable for soil N diagnosis in wheat. Nan concentration had a greater impact on the CY than did NO_3^--N content, as it explained 41% of yield variability (**Table 1**). When NO_3^--N availability and Nan were combined the estimation of CY was improved significantly (**Table 1** and **Figure 3a**).

Pre-plant NO_3^--N content was not a good predictor of N exported in grain. However, when Nan was incorporated into the model, the estimation was improved from 11 to 58% (**Table 1** and **Figure 3b**).

Nan Experiments in Corn

Nan's contribution to the N diagnosis in corn was evaluated for six years at 14 sites within the provinces of Santa Fe and Buenos Aires (**Figure 2**). In these respective regions, the

Table 1. Models to estimate the yield (kg/ha) in control plots and the N exported in wheat grain, and the relative yield (%) of corn at planting and six-leaf (V6). Sources: Reussi Calvo et al., 2013a; Sainz Rozas et al. (2008).

Models for wheat (n = 28)	Adjusted r^2
Control yield = 3,609+ 18.810 x NO_3–N	0.24
Control yield = -1,555+ 80.732 x NO_3–N- 0.38 x (NO_3–N)^2 + 47.423 x *Nan*	0.66
Grain N = 57.8+ 0.172 x NO_3–N	0.11
Grain N = 19.1+ 0.134 x NO_3–N + 0.662 x *Nan*	0.58
Models for corn (n = 26)	**Adjusted r^2**
Relative yield at planting = 61.7+ NO_3–N x 0.234	0.37
Relative yield at planting = 53.8+ NO_3–N x 0.182 + 0.213 x *Nan*	0.57
Relative yield at V6 = 41.9 + NO_3–N x 0.653	0.56
Relative yield at V6 = 41.5 + NO_3–N x 0.492 + 0.193 x *Nan*	0.73

Nan = anaerobic N (mg/kg, 0 to 20 cm).
For wheat and corn, NO_3^--N at planting is kg/ha, at 0 to 60 cm.
For corn, NO_3^--N at V6 is kg/ha, at 0 to 30 cm.

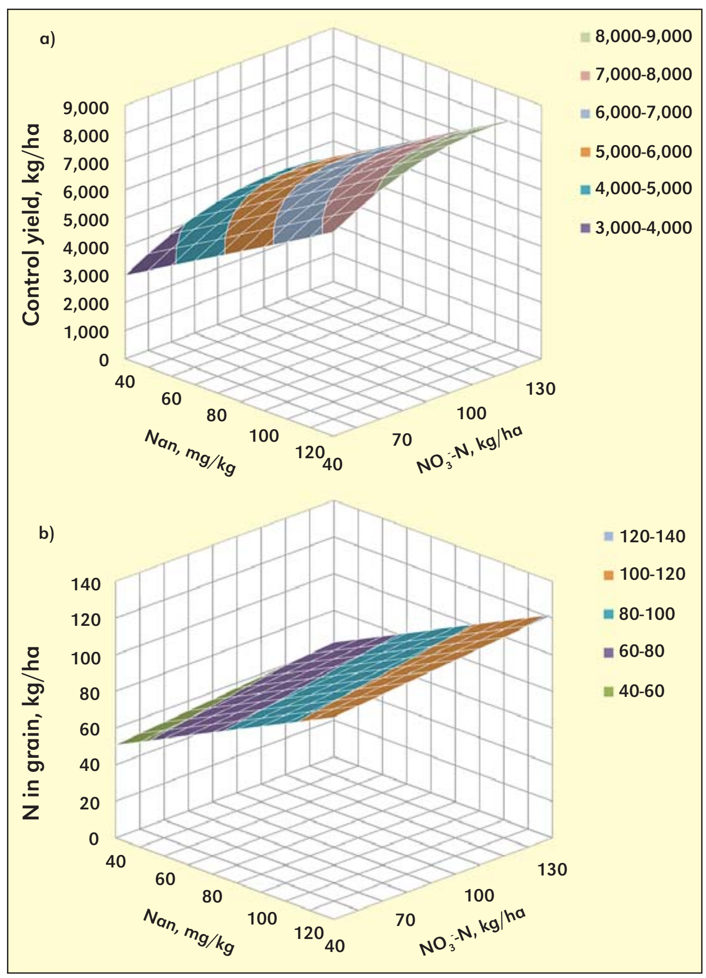

Figure 3. Contribution of Nan and preplant NO_3^--N to the yield (a) and N exported in wheat grain (b). Adapted from Reussi Calvo et al. (2013a).

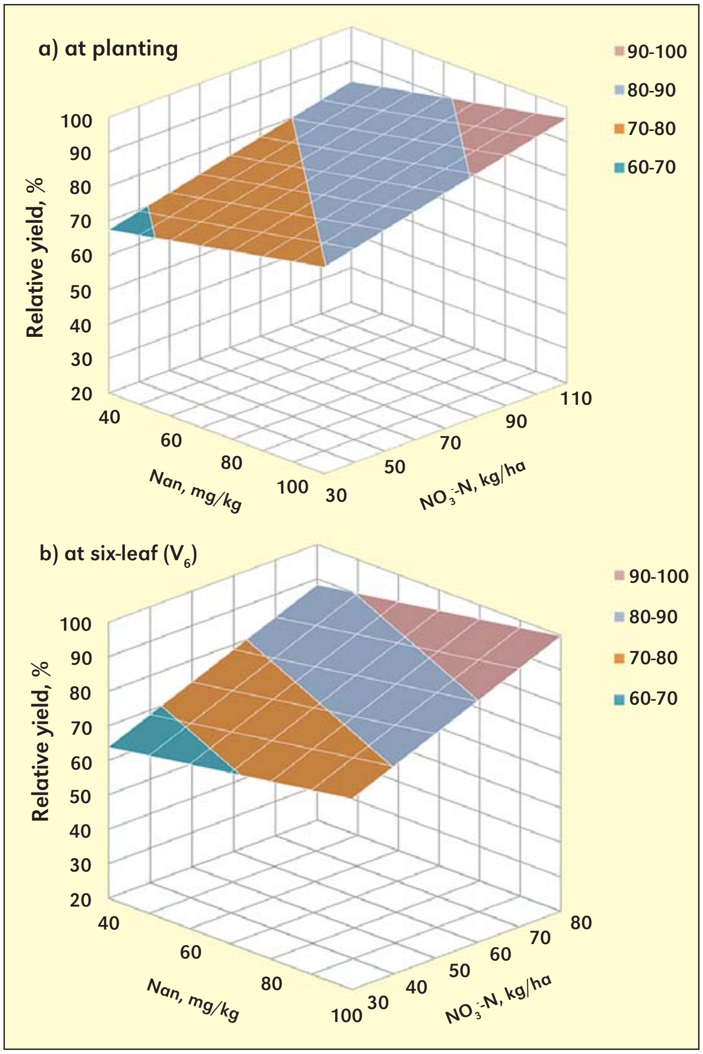

Figure 4. Contribution of Nan and NO_3^--N content to the relative performance of corn sampled at planting (a) and at six-leaf (V_6) stage (b). Adapted from Sainz Rozas et al. (2008).

soil NO_3^--N test already explained 53% and 45% of the crop yield variability (Reussi Calvo et al., 2013b). When Nan was included in the model the predictor improved by 5% in Santa Fe and 16% in Balcarce. The larger contribution of Nan to corn yield estimation in Balcarce is explained by the region's lower temperatures and higher OM contents, which would limit the overall predictive capability of the soil NO_3^--N test that is performed at planting.

Nitrogen response in an environment with low Nan. From left to right 0, 100, 200, and 300 kg N/ha.

A network of 26 experiments conducted in the southern Pampas (Sainz Rozas et al., 2008) determined that the combined measurement of soil NO_3^--N content with Nan improved the estimation of N availability at planting and V6 (**Table 1**). Furthermore, Nan has a greater partial contribution to the RY sampling at V6 than at planting (**Table 1**; **Figure 4a** and **4b**). The use of NO_3^--N at planting or V6 may be a relatively reliable methodology for predicting corn response to N fertilization in the Pampas. However, the predictive value is increased when Nan is incorporated for N diagnosis. BC

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4R Nutrient Stewardship for Sunflower Crops in Northwest China

By Shutian Li, Debao Tuo and Yu Duan

Nutrient imbalance following over- and under-application of some nutrients has restricted sunflower production in Northwest China. A review of research demonstrates how the 4R Nutrient Stewardship approach can lead to better performing sunflower cropping systems.

Traditionally, fertilizer management within the 680,000 ha of sunflower grown in Inner Mongolia (IMAR) and the rest of northwest China has always focused on the application of any available manures along with N and/or P fertilizers. It is known that P fertilizers are commonly overused in the region, while less than 10% of sunflower ever receives K fertilizer (Tuo et al. 2010). Even in areas where K fertilizer is applied, the rates provide less than 30% of the crop's need. The research-based information below is organized according to the principle's of 4R Nutrient Stewardship …identifying the right sources of nutrients at right rates, time and place …in order to increase sunflower yields, farmer profits, and improve nutrient use efficiency within northwest China.

What is the Right Source?

Appropriate fertilizer sources for sunflower depend on soil nutrient status, irrigation method used, crop growth stage, and availability of organic nutrient sources. Sustained high yields in the IMAR region require balanced fertilization with a focus on soil-test-based S and Zn applications as well as Mn and B (**Table 1**). Low soil K availability commonly restricts plant growth and reduces sunflower yield and quality.

In a S-deficient soil, $(NH_4)_2SO_4$, SSP and K_2SO_4 may be the more appropriate fertilizer sources for N, P and K, because these sources will also supply S along with the intended nutrients. In fact, field study in IMAR shows that K_2SO_4 application can lead to higher profitability over KCl (**Table 2**). Jiang (2011) showed that applications of B and Zn increased seed yields of sunflower by 9.9 to 11% on soils low in these nutrients. Jabeen et al. (2013) indicated that foliar sprays of boric acid (H_3BO_3) and manganese chloride ($MnCl_2$) led to significant increases in seed number, seed weight, and oil content of seeds under non-saline or saline water irrigation practices. Yassen et al. (2011) studied the response of sunflower plants to two N fertilizers irrigated by agricultural drainage water and found that plant growth and yield increased by using NH_4NO_3 instead of $(NH_4)_2SO_4$.

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Zn = zinc; Mn = manganese; B = boron; SSP = single superphosphate; K_2SO_4 = potassium sulfate; KCl = potassium chloride; DAP = diammonium phosphate; MAP = monoammonium phosphate; NH_4NO_3 = ammonium nitrate; $(NH_4)_2SO_4$ = ammonium sulfate.

Sunflower covers almost 700,000 ha in northwest China, which represents over 70% of China's production.

Fertilizer efficiency can be improved by integration with organic sources as they improve soil physical properties and also supply a range of essential nutrients. Field studies by Reddy and Ahmed (2009) showed that the application of an organic sources along with 75% N from an inorganic source helped maintain good soil and plant nutrient statuses and also increased the yield and yield attributes of sunflower. Subha and Giri (2005) also indicated that the use of organics and bio-resources could reduce the recommended rates of fertilizers by nearly 30%. Basal application or topdressing of highly soluble fertilizers such as urea, DAP or MAP, and KCl or K_2SO_4 can rapidly supply important nutrients to sunflower for use during rapid growth periods.

… the Right Rate?

Differences exist in N, P and K requirements of sunflower due to different varieties and locations. However, K is consistently needed in larger amounts than N or P. Generally, an average of 7.4 kg N, 1.9 kg P_2O_5 and 16.6 kg K_2O are needed to produce 100 kg seed of oil sunflower, while an average of 6.2 kg

Table 1. Some chemical properties of experimental soils in Inner Mongolia.

	pH	OM %	NH_4-N	NO_3-N	P	K	S	Fe	Cu	Mn	Zn	B
			mg/L									
Min	8.2	0.2	0.4	10.9	3.2	75.0	0.0	6.1	1.0	2.8	0.7	1.0
Max	9.1	2.0	35.8	80.2	40.2	149.0	176.8	18.8	78.9	14.5	2.5	12.5
Mean	8.6	0.5	10.1	24.9	22.8	100.2	36.8	12.4	15.5	8.9	1.6	3.7

*All parameters were analyzed using ASI procedure (Portch and Hunter, 2005).

Table 2. Effect of K source on sunflower yield and economics (IMAR, 2012).

Treatment	Seed yield, kg/ha	Yield increase over CK, %	Gross income, US$/ha	Fertilizer cost, US$/ha	Benefit from fertilizer, US$/ha	Benefit from K, US$/ha
CK	2,999c	-	3,869	0	-	-
-K	3,609b	20.3	4,656	225	562	-
KCl	3,945a	31.5	5,089	330	890	328
K_2SO_4	4,039a	34.7	5,210	378	964	402

*Fertilizer rates of N-P_2O_5-K_2O used were 225-75-135 kg/ha, respectively; prices used were: N = US$0.73/kg, P = US$0.81 P_2O_5/kg, K (KCl) = US$0.78 K_2O/kg; (K_2SO_4) = US$1.13 K_2O/kg, and sunflower seed = US$1.29/kg.

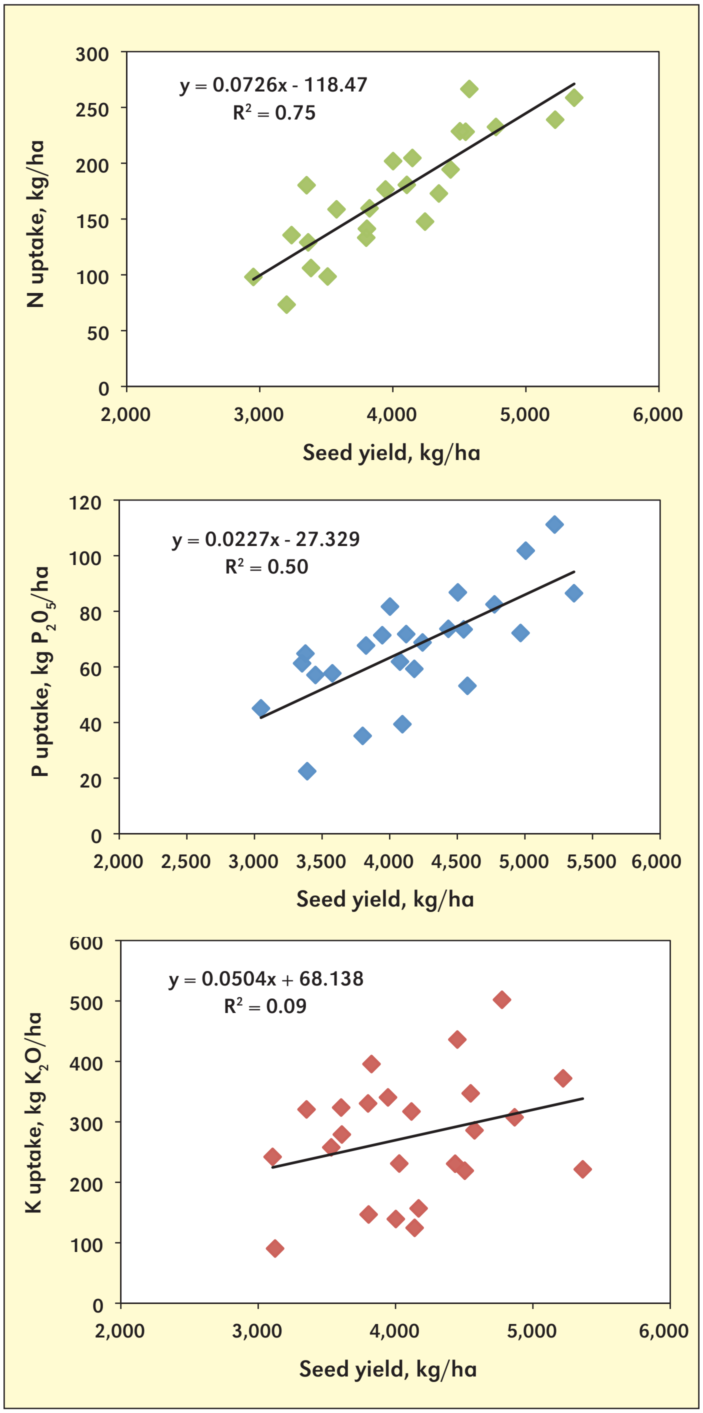

Figure 1. Relationship between sunflower seed yield and N, P, and K uptake.

N, 1.3 kg P_2O_5 and 14.6 kg K_2O are required for producing 100 kg seed sunflower (Jiang, 2011).

IPNI research in the IMAR showed that the average N, P_2O_5 and K_2O uptake required to produce 100 kg seed (at an average yield level of 4,360 kg/ha) was 4.8, 1.7 and 7.2, respectively (**Table 3**). Average agronomic efficiencies (kg seed/kg nutrient) for N, P_2O_5 and K_2O in this study were 3.6, 4.8 and 3.5, respectively. Significant correlation existed between seed yield and N and P uptake (**Figure 1**). Recommended rates were estimated to be 245 kg N/ha and 86 kg P_2O_5/ha for a target seed yield of 5,000 kg/ha. No relationship existed between seed yield and K uptake, but the apparent balance could be used to determine the recommended K rate. For example, if the target seed yield was 5,000 kg/ha, sunflower used 360 kg K_2O/ha (5,000 x 7.2/100). The average seed yield in K omission plots conducted by IPNI was 3,879 kg/ha and the mean K uptake efficiency was 48%, so a yield increase of 1,121 kg/ha (5,000 - 3,879) would need 168 kg K_2O/ha (1,121 × 7.2/0.48/100). Fertilizer P and K recommendations in the region are commonly based on soil testing and P and K application can be recommended for sunflower at the regular yield levels (4,000 to 5,000 kg/ha) according to **Table 4**.

… the Right Time?

The uptake of N, P and K varies considerably with growth stage of sunflower. At the seedling stage, sunflower has weak roots and poor nutrient uptake ability, and therefore, sufficient nutrient supply is critical at this growth stage. Jiang et al. (2011) indicated that about 50, 55 and 50% of accumulated N, P and K were taken up from budding to flowering stage, while about 35, 25 and 25% were taken up after flowering. Li et al. (2009) indicated that for edible sunflower, N uptake was most rapid from budding to flowering, while P and K uptake was most rapid during the flowering stage. For oil sunflower, rapid uptake of N and K occurs at budding while P uptake peaks from flowering to maturity.

IPNI research in the IMAR has indicated that rapid accumulations of N, P and K occur during 38 to 71 days after emergence (DAE). Although some of the accumulated N, P and K in vegetative tissues transferred to seeds after 56 DAE, sunflower plants still took up 13, 23 and 11% of total accumulated N, P and K after 56 DAE (**Figure 2**). These data suggest that adequate nutrient supply is still important in later growth stages of sunflower. Therefore, topdressing is necessary, and the right time for topdressing N and K is around 38 DAE when the flower disks begin to appear. Vijayakumar and Ramesh (2005) also indicated that split N application resulted in higher growth and seed yield of rainfed sunflower when compared with full basal application before planting.

… the Right Place?

Fertilizers are generally applied in the field by banding, surface broadcasting, broadcasting followed by incorporation, or hole application near the crop row. Banding and broadcasting of fertilizer can be done as basal application before plant-

Table 3. Nutrient uptake and efficiency of sunflower in Inner Mongolia (2008-2012).

	Nutrient applied, kg/ha			Seed yield, kg/ha	Nutrient uptake for producing 100 kg seed, kg			Agronomic efficiency, kg/kg			Nutrient recovery efficiency, %		
	N	P_2O_5	K_2O		N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Mean	206	91	140	4,362	4.76	1.68	7.20	3.6	4.8	3.5	35.5	16.2	47.7
Max	285	165	180	5,363	5.82	2.13	10.51	10.8	7.1	7.2	60.7	23.8	63.0
Min	150	60	60	3,352	3.51	0.93	3.48	1.8	2.5	1.7	23.3	8.4	32.5

Table 4. Fertilizer P and K rate recommendations for sunflower based on soil testing (Bai et al., 2007).

Soil available P, mg P/L	0-7	7-12	12-24	24-40	40-60	>60
Recommended P, kg P_2O_5/ha	180	150	105	75	45	0
Soil available K, mg K/L	0-40	40-60	60-80	80-100	100-140	>140
Recommended K, kg K_2O/ha	255	225	195	150	105	60
Analysis by ASI procedure (Portch and Hunter, 2005).						

ing. Many smallholder farmers do post-emergence fertilizer application by surface broadcasting. Where used, hole application is suitable for topdressing during the crop growth and can save fertilizer because of reduced nutrient losses compared to surface broadcasting. Banding or hole application of fertilizers should be done 6 to 10 cm away from seeds or plant roots to avoid damaging them (Jiang, 2011). For hole application, the depth of the hole depends on fertilizer source and soil moisture. Deep application of fertilizers should be adopted for volatile fertilizers like ammonium bicarbonate or liquid ammonia. In dry seasons, fertilizers should be at greater depth or combined with irrigation to avoid losses and improve their use efficiency.

Summary

The crop production and environmental protection goals of northwest China's sunflower growers are achievable through improved nutrient management. The nutrient needs of sunflower have been defined through local research. The 4R Nutrient Stewardship approach outlines the best options to meet those crop demands.

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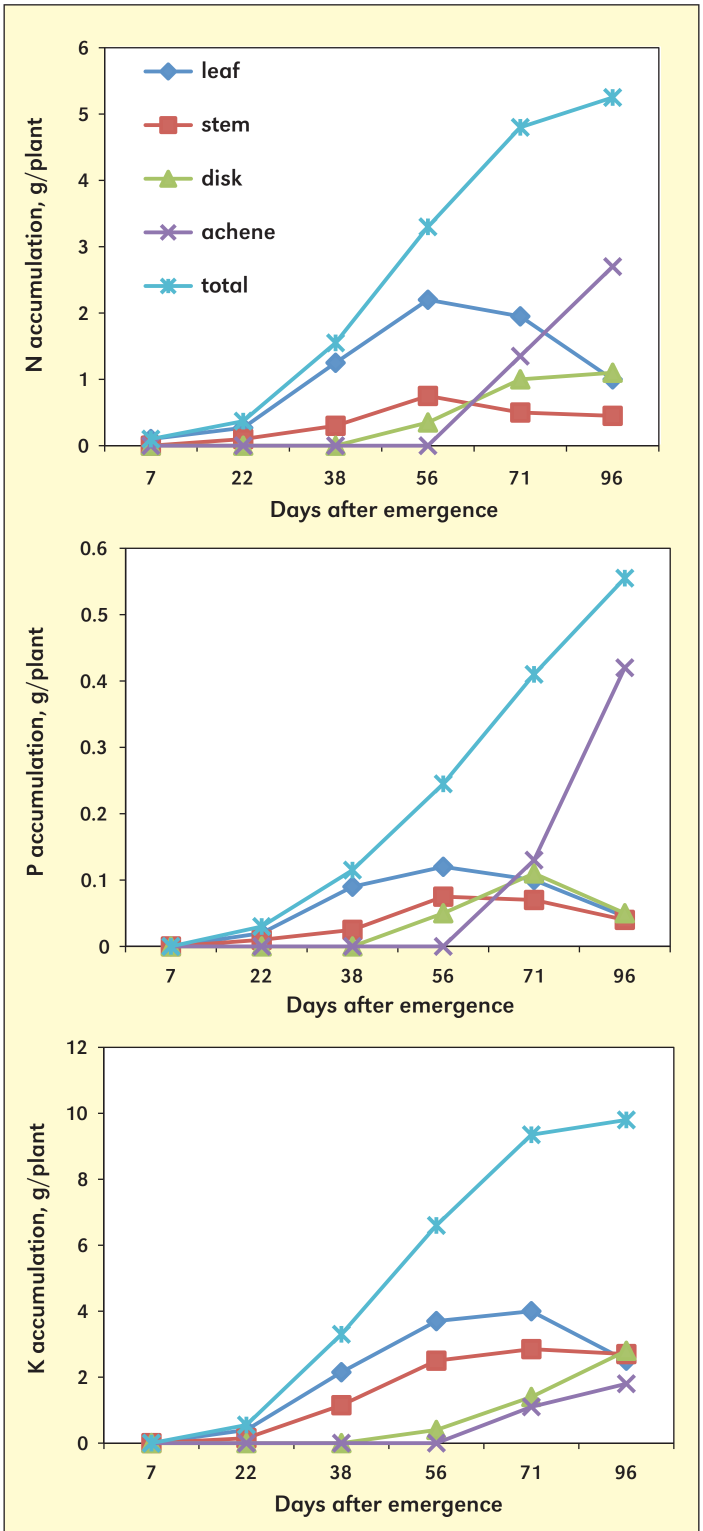
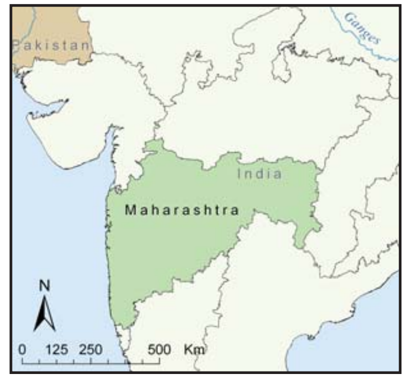


Figure 2. Nutrient N, P and K accumulation by sunflower plants.

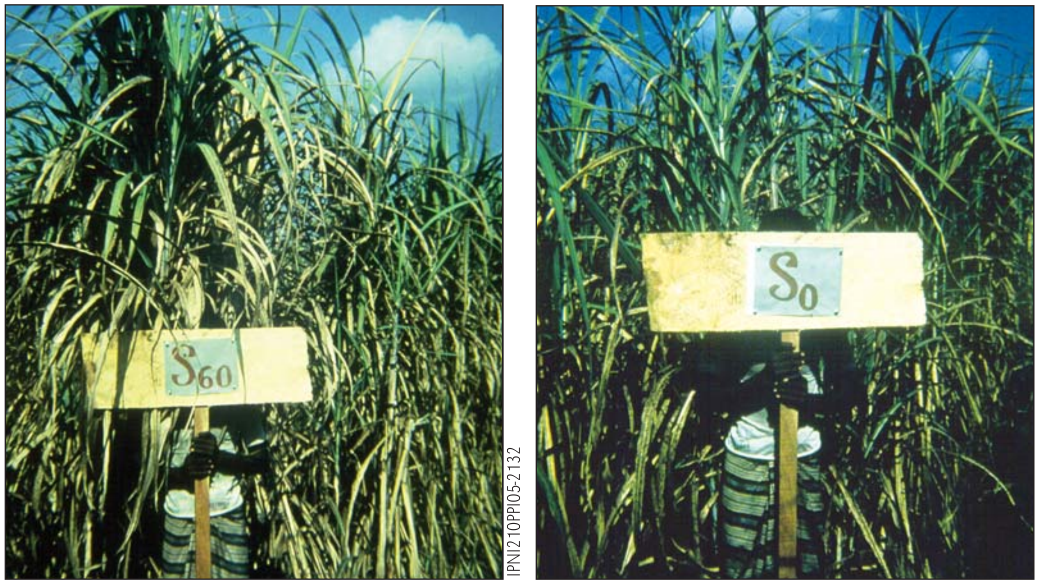
Meeting the Nutrient Demands of Modern Sugarcane Varieties

By D.B. Phonde, P. S. Deshmukh, M.W. Pawar, P.V. Ghodake, B.V. Undare, Harmandeep Singh Khurana, and Aliaksei Shcharbakou



Traditional practice within the average sugarcane field in Maharashtra is producing yields that are far below their potential. This study tests the current fertilization recommendation scheme with a modern crop variety to determine the viability of increasing the supply of nutrients that are commonly known to be either yield limiting or entirely avoided by growers.

In the western State of Maharashtra, the sugarcane agro-industry is second only to cotton in terms of economic importance. The crop has brought many desirable changes in social, economic, educational, and political life throughout its rural areas. High yields are possible and the three planting seasons, and ratoon crops sprouted from a previously harvested crop, can produce 200 to 270 t/ha. However, the state's average cane yield is only 85 t/ha. An important part of bridging this yield gap is adequate nutrient supply. Numerous research reports indicate that nutrient deficiencies are increasingly prevalent in cane-growing soils of Maharashtra amidst a lack of emphasis on maintaining soil fertility (Phonde et al., 2005). The impact of high-yielding varieties is an additional concern, as current nutrient recommendations should consider both the potential for both declining soil fertility as well as increasing crop demand.



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From the IPNI Photo Archive (circa 1990): Sulfur application at 60 kg/ha provides a large growth response (left) in the sugarcane variety of the day. The zero S control is shown on the right.

The study below was designed to evaluate the effects of macro-, secondary-, and micro-nutrients on crop yield, quality and economics on a new high-yielding sugarcane variety. Previous yield trials with this variety show a 20% yield advantage compared to other commonly used varieties.

A split-plot design field study with three replications was carried out from 2009 to 2011 at Manjari and Warna in Maharashtra. Main treatments included a state recommended fertilizer dose (RDF) of 340-170-170 kg N-P_2O_5-K_2O/ha, which was tested against 125%, 150% and 175% of the RDF (**Table 1**). Sub-treatments included a control with NPK but no secondary or micronutrients, as well as five combinations of S, Fe, Zn, B, and Mn—each applied at its recommended rate.

Results

Cane yields increased significantly with increasing rates of NPK compared to the RDF (**Table 1**). While the highest cane yield at Manjari was obtained with 150% RDF treatment, the highest yield at Warna was obtained with 175% RDF. In Manjari, S3 (S+Fe+Zn) significantly increased cane yield over the control, but yields were not significantly different from the application of S alone. In Warna, S4 (S+Fe+Zn+B) significantly increased cane yields over the control, but its effect was not significantly different from S3.

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Fe = iron; Zn = zinc; B = boron; Mn = manganese; CCS = commercial cane sugar; ₹ = Indian Rupee.

Commercial cane sugar yields, on the other hand, showed no significant response to NPK application rates above the RDF or to further addition of secondary and micronutrients (**Table 1**). Juice quality parameters such as brix and pol (**Table 2**) as well as purity and CCS % (not shown) responded in a similar manner. Ayub et al. (1999) obtained similar results in their research where sugarcane yields increased with the application of higher fertilizer rates, but there was no change in the CCS yields or any of the juice quality parameters.

The economics of NPK fertilization followed a pattern similar to cane yields (**Table 3**) with significantly higher net returns obtained with 150% and 175% RDF treatments in Manjari and Warna, respectively. Similarly, S, Fe, Zn and B (S4) gave the best economic response to fertilization at Manjari, while S, Fe, Zn, B, and Mn (S5) gave the best economic response at Warna. Thus, a balanced fertilization approach that included the site-specific application of secondary- and micro-nutrients proved superior to just the application of NPK alone.

Summary

Cane yields and net returns increased with NPK application beyond that currently recommended for sugarcane in

Table 1. Cane and commercial cane sugar (CCS) yields as affected by different rates and nutrient combinations at Manjari and Warna, Maharashtra, India.

Treatments	---- Cane yield, t/ha ---- Manjari	Warna	Mean	---- CCS yield, t/ha ---- Manjari	Warna	Mean
NPK (M)						
M1 (100% RDF)	92.9a	92.0a	92.5	12.8a	14.0a	13.4
M2 (125% RDF)	99.4b	93.6b	96.5	11.3a	14.8a	13.1
M3 (150% RDF)	107c	98.1c	102	11.3a	15.4a	13.3
M4 (175% RDF)	108c	105d	107	13.3a	15.6a	14.4
Secondary and Micronutrients (S)						
Control	99.0a	94.4a	96.8	13.0a	14.3a	13.6
S1 (S)	102ab	94.8a	98.1	12.2a	14.5a	13.3
S2 (S+Fe)	99.5a	96.6a	98.0	11.8a	14.4a	13.1
S3 (S+Fe+Zn)	103b	97.3abc	100	11.5a	16.1a	13.8
S4 (S+Fe+Zn+B))	105b	99.1bc	102	12.1a	15.7a	13.9
S5 (S+Fe+Zn+B+Mn)	104b	101c	102	12.4a	14.8a	13.6
Interaction M x S						
	NS	NS	-	NS	NS	-

Means in the same column followed by the same letter are not significantly different at p = 0.05.
Recommended fertilizer rates include: 340-170-170 kg N-P_2O_5-K_2O/ha; 60 kg S/ha, 25 kg $FeSO_4$/ha; 20 kg $ZnSO_4$/ha; 5 kg Borax/ha; 10 kg $MnSO_4$/ha.
Control included 425-210-210 kg N-P_2O_5-K_2O/ha.
High-yield variety (Co VSI 9805)

Table 2. Response of sugarcane to levels of NPK, secondary, and micronutrients on Brix and Pol (sucrose) % at Manjari and Warna, Maharashtra, India.

Treatments	------- Brix, % ------- Manjari	Warna	Mean	------- POL, % ------- Manjari	Warna	Mean
NPK (M)						
M1 (100%RDF)	19.0a	22.6a	20.6	17.3a	20.8a	19.1
M2 (125%RDF)	19.0a	22.0a	20.5	17.4a	20.6a	19.0
M3 (150%RDF)	18.6a	21.3a	19.9	18.0a	20.0a	19.0
M4 (175%RDF)	19.0a	21.4a	20.2	17.7a	20.0a	18.9
Secondary and Micronutrients (S)						
Control	19.0a	21.5a	20.2	18.2a	20.0a	19.1
S1 (S)	19.0a	21.3a	20.1	17.6a	19.9a	18.7
S2 (S+Fe)	19.2a	21.4a	20.3	17.8a	20.0a	18.9
S3 (S+Fe+Zn)	18.8a	22.9a	20.8	16.8a	21.6a	19.2
S4 (S+Fe+Zn+B))	18.4a	22.2a	20.3	17.9a	20.8a	19.4
S5 (S+Fe+Zn+B+Mn)	18.7a	21.2a	19.9	17.3a	19.7a	18.5
Interaction M x S						
	NS	NS	-	NS	NS	-

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

Maharashtra, but the response was site-specific. Cane yield response to secondary and micronutrient application also varied between the two locations. Commercial sugar yield and sugarcane juice quality parameters were not affected by any of the experimental approaches. In summary, a balanced approach that includes the site-specific application of macro- as well as secondary- and micro-nutrients is likely to meet the demands of modern sugarcane varieties and generate better results for growers. BC

Table 3. Economic evaluation of different levels of sugarcane fertilization at Manjari and Warna, Maharashtra, India.

Treatments	Gross returns, '000 ₹/ha	Cost of Cultivation, '000 ₹/ha	Net returns, '000 ₹/ha
Manjari			
NPK (M)			
M1 (100%RDF)	167a	81	86a
M2 (125%RDF)	180b	83	97b
M3 (150%RDF)	192c	86	106c
M4 (175%RDF)	195c	88	107c
Secondary and Micronutrients (S)			
Control	178a	83	95a
S1 (S)	183b	84	99b
S2 (S+Fe)	179a	84	95a
S3 (S+Fe+Zn)	186bc	85	101bc
S4 (S+Fe+Zn+B))	189c	85	104c
S5 (S+Fe+Zn+B+Mn)	187c	86	101bc
Warna			
NPK (M)			
M1 (100%RDF)	166a	81	85a
M2 (125%RDF)	168a	83	85a
M3 (150%RDF)	177b	86	91b
M4 (175%RDF)	189c	88	101c
Secondary and Micronutrients (S)			
Control	170a	83	87a
S1 (S)	171a	84	87a
S2 (S+Fe)	174ab	84	90ab
S3 (S+Fe+Zn)	175abc	85	90ab
S4 (S+Fe+Zn+B))	178bc	85	93bc
S5 (S+Fe+Zn+B+Mn)	182c	86	96c

Means in the same column followed by the same letter are not significantly different at p = 0.05.
*Economic returns and cost of cultivation were calculated using the following: Minimum support price of sugarcane = ₹2.5/kg; Costs of fertilizer N, P, K, S, Fe, Zn, B, and Mn = ₹10.5, 16.5, 7.5, 26.5, 22, 20, 34, and 28/kg, respectively; Labor cost = ₹105/day in addition to irrigation and pesticide costs. US$1= ₹60.

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Increasing Soybean Yields: Brazil's Challenges

By Eros Francisco, Gil Câmara, Valter Casarin, and Luis Prochnow

Average soybean yield has increased over recent decades in many areas of the world, but a plateau seems to have been reached in some situations, Brazil being a typical case. This article summarizes the main reasons why this has happened in the world's second largest soybean producing country, and what farmers need to overcome to break the current barrier. Also, a few lessons on general common practices contributing to high yields in the U.S. are outlined.

Brazilian soybean production has the potential to become the largest in the world. In 2013, its production ranked second at 81.5 million t (CONAB, 2013). The U.S. led with 88.6 million t (USDA, 2013) while other major producers include Argentina, China and Índia (FAO, 2013). Since the 1990s there has been a significant increase in land cultivated to soybean in Brazil, especially due to the development of new areas in the Midwest (**Figure 1**).

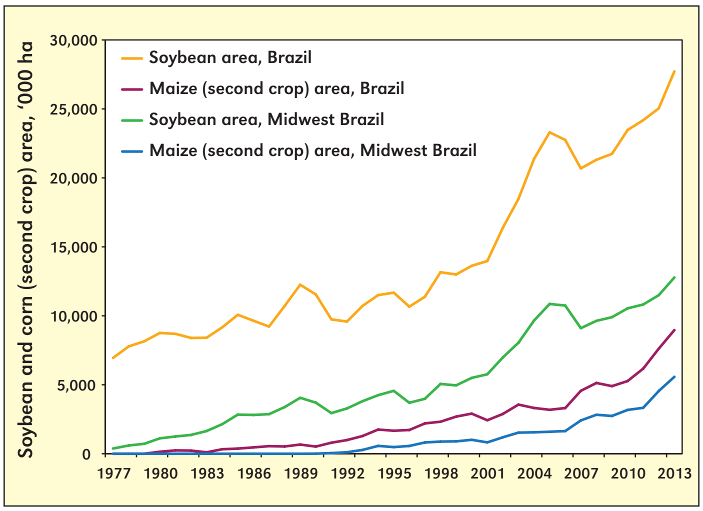

Figure 1. Soybean and maize second crop cultivated land in Midwest Brazil and Brazil from 1977 to 2013. Source: Conab, 2013.

Favorable soil and climatic conditions, genetic improvement, government loans, adoption of technology, and intensive farmer effort have all contributed to the success of soybean production in the Brazilian Savannah (Cerrado). Nevertheless, soybean production systems face real challenges including adverse weather (drought or flooding), new disease and pest issues, and the adoption of sub-par management practices.

Soybean production systems in Brazil were basically unchanged until the late 1990s, with soybean grown mainly under conventional tillage systems from early November to late March or April. After 2000, farmers started to seed earlier in the season (October), adopt no-tillage rapidly, and began growing cover crops after soybean harvest. This system has spread and currently about 50% of the soybean area in the Cerrado during the summer turns into maize second crop, 5% turns to cotton second crop, and other areas are covered with different grain or cover crops, such as sorghum, beans, millet, brachiaria grass, and sunn hemp.

The technological evolution of agriculture in the Cerrado during the 1990s was crucial to reach the current average soybean yield of 3,000 kg/ha. Genetic improvements were able to deliver new varieties adapted to low latitudes, and resistant to *Phytophtora* (Stem Canker) and *Heterodora glycines* (cyst nematode). New fungicide/insecticide molecules were developed as well as more efficient strains of *Bradyrhizobium japonicum*, all in parallel with better nutrient management practices.

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; C = carbon; B = boron; Mo = molybdenum; Co = cobalt.

The strong expansion of cultivated area has been beneficial in many aspects, but is also creating some challenges: (i) soil fertility management in a new agriculture frontier, especially with sandy soils; (ii) crop disease management due to the introduction of Asian Rust (*Phakopsora pachyrhizie*) in 2001; (iii) soil compaction in old no-till production fields; (iv) high population of nematodes, especially the soybean cyst nematodes and pratylenchus nematodes (*Pratylenchus brachyurus*); and (v) new pests (**Figure 2**).

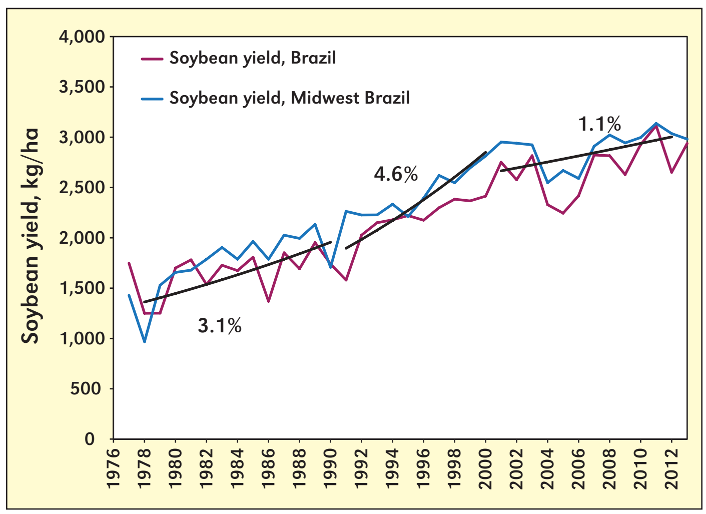

Figure 2. Soybean yield increases in Midwest Brazil and Brazil from 1977 to 2013. Source: Conab, 2013.

Agronomic Challenges for High Yielding Soybean Systems

Early Seeding and Short Maturity Cultivars

Soybean grain yield is positively correlated with variety maturation cycle when other factors are kept the same (latitude, seeding time and crop management). Therefore, under the same soil and weather conditions, long cycle soybean groups tend to be more productive than short cycle groups because of higher leaf area index to intercept light and fix C, and also more extensive root systems to take up more nutrients, fix N, and accumulate greater amounts of biomass. Drastically advancing time of seeding leads to a growing season with shorter days, which tends to depress yields even more. Some reports indicate a 5 to 10% loss in yield depending on the interaction between crop variety and seeding time.

Biological N Fixation

Nitrogen is a critically important nutrient for soybean. Nitrogen levels in the grain range from 4.5 to 6.5%, while the stover is generally 3.0% N. Soybean generally requires about 240 kg N/ha to yield 3,000 kg/ha (Hungria et al., 2001). Most of this N is supplied by biological fixation (BNF).

To study soybean system efficiency, Oliveira Jr. et al. (2010) used results for his soybean N budget from Alves et al. (2006). An average yield of 3,244 kg/ha was associated with 228 kg N/ha in the total dry matter yield, of which 194 and 35 kg N/ha came from BNF and the soil, respectively. With a total grain uptake of 183 kg N/ha, the net N budget was only 10 kg/ha.

The authors call attention to factors that depress BNF such as: (i) Mo and Co availability, which has a direct relationship with soil pH and, therefore, liming helps to supply such nutrients to plants; (ii) soil compaction, which negatively impacts soil aeration; and (iii) soil temperature. Important soil management practices such as liming, incorporation of P into the soil profile, and proper crop rotation all promote a good environment for vigorous soybean root systems, while soil compaction and high acidity greatly impact BNF and plant growth.

Soybean root system with (top) and without nodules (bottom) in response to soil management that promotes biological N fixation.

High soil temperatures also have a large impact on BNF. The ideal temperature for *Bradyrhizobium* development is around 25 to 30°C (Bizarro, 2008). **Table 1** shows temperatures observed in a high clay soil (65% clay) during a sunny afternoon in a soybean field at an early growth stage. Temperature of the seedbed zone (2 to 3 cm) was very high in plots without crop residue (60°C or 140°F), while no-till plots with crop residue had much lower temperatures. The impact of high temperatures on BNF can be even more detrimental in exposed sandy soils.

Table 1. Soil temperature (°C) in response to soil management and depth.

Soil management	- - - - - Depth, cm - - - - - 0	2	4	6	8
No-till system	41.0a	34.2a	32.9a	32.5a	32.1a
Conventional tillage	60.2b	45.2b	42.9b	41.2b	40.0b

Means followed by the same letters do not differ within columns ($p = 0.05$).
Source: Research Foundation MT, 2012 (unpublished data).

Broadcast P Application

In past years, there has been a large-scale adoption of broadcasting P fertilizers in Brazil. There is a lack of official statistics, but a short survey made by IPNI Brazil Program during a national webinar showed that 35% of the attendees broadcasted P over their entire farm, while 51% use the practice on at least half of their farm.

Broadcasting P is not a new technique, but its general adoption is more associated with the need to speed up the seeding process due to changes in the production systems (i.e., relying on early seeding dates and harvesting as a way to escape Asian Rust) and also, to increase the area available for a maize second crop.

Some studies have shown high-yielding soybean with the broadcasting of soluble P fertilizers (Kappes et al., 2013; Oliveira Jr. et al., 2011; Souza and Lobato, 2003). However, Oliveira Jr. and Castro (2013) emphasized caution since (i) even in high fertility soils banded application has shown yield increases compared to broadcast application, and (ii) continuous broadcast application of P fertilizer in no-till systems will lead to the formation of a gradient of available soil P within the profile since P is not mobile in most soils. The authors showed, based on a two year study comparing P rates and placement, that there is a positive relationship between soybean yield increase and higher available soil P in the subsurface (10 to 20 cm) layer (**Figure 3**). The adoption of broadcast application of P fertilizer needs careful evaluation of the soil chemical conditions in order to benefit soybean yield. Adoption of the practice in the absence of this information does not meet with agronomic recommendations.

Soybean on Sandy Soils

Sandy soils (< 15% clay) in Brazil are generally not recommended for annual cropping due to limitations in nutrient availability, water holding capacity, and erosion susceptibility. Nevertheless, the expansion of cultivated land in Brazil made farming these soils an important reality. Grain production on sandy soils is a great economic challenge. The most limiting nutrients in these soils include the most mobile, which are N, K, B, and S.

Again, with no crop residue on the surface, these soils are exposed to very high temperatures with great consequences for BNF. Nitrogen deficiency symptoms are often visible in very early growth stages (V_2/V_3). The conservation of crop residue promotes nutrient cycling, which is crucial for sustainability in sandy soils, and particularly affects the K supply to plants and makes the timing of K application crucial. Soybean plants

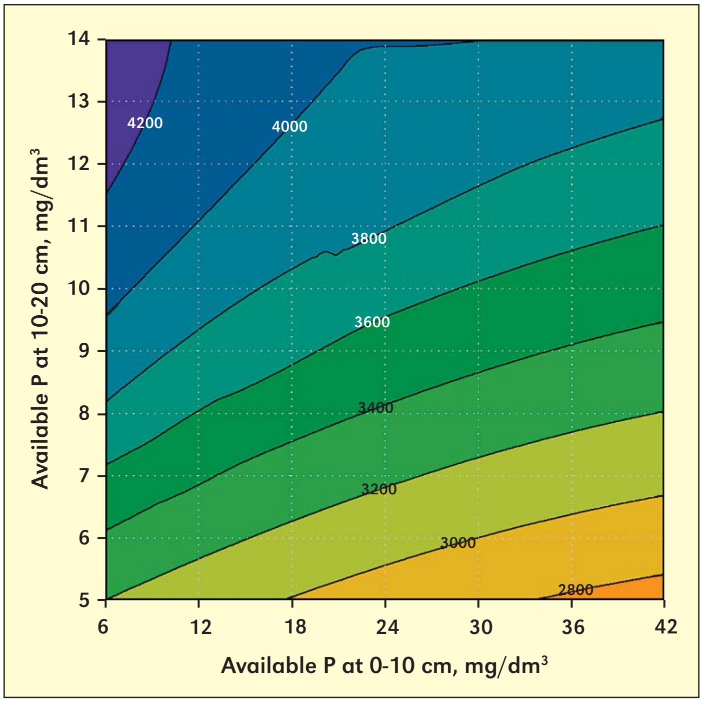

Figure 3. Soybean yield in response to available P (Mehlich 1) in the 0 to 10 cm and 10 to 20 cm soil layers. Source: Oliveira Jr. and Castro, 2013.

Deficiency symptoms of N (top) and K (bottom) in soybean plants grown on exposed, sandy soils.

can show K deficiency symptoms in early growth stages where fertilizer application is postponed.

Early Desiccation for an Early Harvest

Early harvest of soybean fields in Midwest Brazil is increasingly attractive for farmers seeking a second crop in the season, which is mostly maize, but has led growers to make wrong decisions regarding the timing of soybean desiccation. This technique was developed to control weeds and homogenize maturity in plants suffering with green stems or leaf retention. According to EMBRAPA (2011), desiccant application before R_7 growth stage (beginning of maturity) can cause dramatic decreases in yield.

Final Considerations

High soybean yields in Brazil are common in regions where the agronomic practices are used correctly. Nevertheless, we consider that yields between 3.6 to 4.0 t/ha are likely 75 to 85% of attainable yield, and therefore some important questions are raised. How far are we from maximum yield? How much of the complex set of interactions between the cropping system and the production environment is understood?

Ecological intensification of the cropping system represents a huge advantage for regions of the world where two or more crops can be grown in a season, but it is highly dependent on a fast operational system to crop vast areas in a short time. It seems that in some cases agronomic practices hold a second place priority in favor of the overall scale of production. BC

High Soybean Yields in the U.S.

Dr. Valter Casarin, Deputy Director of the IPNI Brazil Program, recently toured the main soybean regions in U.S. looking for common practices leading to high yields. Following is a list of his main observations, which might be of use in other parts of the world.

Cultivar selection: farmers carefully select cultivars based especially on maturity cycle, resistance to diseases and pests, and consistency in yield through time.

Planting date: The target is to seed as early as possible and take advantage of water availability, but late enough in the season as to avoid frost.

Plant population: In general, seeding in narrow rows is leading to higher yields due to more rapid covering of the soil, higher interception of solar radiation, and less problems with weeds.

Weed control: Several field experiments in different regions define the best herbicides for each cultivar. In some situations, weed control can significantly decrease nematodes and some diseases and insects.

Nitrogen in soybean: Careful attention is necessary to prevent a decrease in BNF by the presence of too much available soil N, but in some regions, especially in sandy soils, farmers do apply some supplemental N during the crop's late development stage (R_3).

Soil fertility: Higher yields demand close attention to soil fertility status to avoid a lack of proper nutrient supply to plants. Some advantages have been noticed with the application of banded P to soils, even when availability is medium to high. Sulfur and micronutrient availability needs also to be carefully evaluated.

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IPNI Crop Nutrient Deficiency Photo Contest—New Rules for 2014

The International Plant Nutrition Institute (IPNI) is continuing its sponsorship of its plant nutrient deficiency photo contest during 2014 to encourage field observation and increase understanding of crop nutrient deficiencies. However, this year our contest features some important changes:

1. In addition to the four nutrient categories (N, P, K and Other Nutrients - secondary and micronutrients), we have added a new **"Feature Crop"** category—in 2014 we are focused on **Hay and Forage Crops**.

Like previous years, we are ready to receive images for all crops from avocado to zucchini, but if you have a great photo of a nutrient deficiency in a forage crop, now is the time to share it.

2. Our new list of prizes is as follows:

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

3. Specific supporting information is required (in English) for all entries, including:

- The entrant's name, affiliation and contact information.
- The crop and growth stage, location and date of the photo.
- Supporting and verification information related to plant tissue analysis, soil test, management factors and additional details that may be related to the deficiency.

"We hope the competition will appeal to practitioners working in the field," said IPNI President Dr. Terry Roberts. "Researchers working under controlled plot conditions are also welcome to submit entries. We encourage crop advisers, field scouts and others to photograph and document nutrient deficiencies in crops."

Photos and supporting information can be submitted until December 12, 2014 (Friday, 5pm EST) and winners will be announced in January of 2015. Winners will be notified and results will be posted at www.ipni.net. BC

Nutrient Uptake and Distribution in Lychee

By L.X. Yao, G.L. Li, B.M. Yang, L.X. Huang, Z.H. He, C.M. Zhou, and S. Tu

Knowing how nutrients are distributed within fruit tree cultivars can lead to better nutrient source, rate, time and place decisions that, in turn, will support tree health and the nutritive value of their fruit. This study detected differences in nutrient need between two cultivars of widespread use, and identified some specific management strategies to address these differences.

Lychee (*Litchi chinensis* Sonn.) is a very popular Asian fruit that originated in southern China (Menzel, 1983) and has now spread throughout many subtropical areas where summers are long and hot. Fruits like lychee, commonly high in K, N, Fe, Zn, and Cu can play an important role in human nutrition. However, despite a long history of cultivation, there has been a lack of systematic research on soil nutrient characteristics in relation to total crop nutrient requirement, uptake ratios, and nutrient use efficiency. Reports from Guangdong suggest a good link between low soil fertility, imbalanced nutrient application and low and variable yields (Chapman, 1984; Li et al., 2009). This study addresses a knowledge gap by examining the nutrient uptake and distribution characteristics of two popular cultivars in order to provide scientific information on best nutrient management practice.

Guiwei is one of the most popular lychee varieties in the world, while Feizixiao is the most widely cultivated variety in China. A healthy 15-year-old Guiwei tree was sampled at fruit maturity from a representative farm orchard in Huazhou, Guangdong with medium to high yield. Similarly, a 15-year-old Feizixiao tree was sampled from another representative farm in Huidong.

Table 1. Selected properties of soils sampled from Guiwei and Feizixiao orchards, Guangdong, China.

Location (variety)	Guiwei	Feizixiao
Texture	Sandy clay loam	Clay loam
pH	4.2	4.6
OM, %	0.9	0.7
Alkali hydrol. N, mg/kg	53	42
Avail. P, mg/kg	46	2
Avail. K, mg/kg	42	44
Exch. Ca, mg/kg	121	115
Exch. Mg, mg/kg	10	9
Avail. S, mg/kg	44	27
Avail. Si, mg/kg	12	11
Avail. Fe, mg/kg	110	44
Avail. Mn, mg/kg	2	2
Avail. Cu, mg/kg	1	0.2
Avail. Zn, mg/kg	0.6	0.6
Avail. B, mg/kg	0.4	0.1
Avail. Mo, mg/kg	0.1	0.1

Soils extractants for N = 1 M NaOH; P = 0.03 M HCl + 0.025 M NH_4F; K = 1 M NH_4OAc; Ca and Mg = 1 M NH_4OAc + 0.05 M EDTA; S = 0.008 M $Ca(H_2PO_4)_2$-HOAc; Si = 0.25 M Citric acid; Fe, Mn, Cu, and Zn = 0.1 M HCl extraction; B = Boiling water extraction; Mo = 0.1 M $H_2C_2O_4$ + 0.175 M $(NH_4)_2C_2O_4$ extraction (Lu, R.K. 2000).

Prior to tree sampling, soil samples were collected from 0 to 50 cm depth, 20 cm away from the water drip line formed by the tree crown. Both soils had low fertility (i.e., very acidic, low in organic matter, deficient in N, K, Mg, Zn, B, and Mo; moderate Ca, Mn, and Si; and adequate Fe and S. Soil P and Cu are adequate under Guiwei trees, but was deficient under the Feizixiao trees; **Table 1**). Four subsamples of the root, trunk, fruit, and leaves were collected from each tree and washed. Fresh weights of each plant organ/tissue were recorded. All samples were rinsed with deionized water and then oven-dried at 70°C. Dry weights were then recorded. The samples were pulverized and analyzed for nutrient content using standard methods.

Biomass Composition

The two cultivars, Guiwei and Feizixiao, produced a total fresh biomass of 189.4 kg and 290.9 kg and fruit yields of 52.5 kg and 62.5 kg, respectively (**Table 2**). Tree trunks accounted for 30.4% of the total biomass for Guiwei and 55.5% for Feizixiao, while the roots only weighed 8.3% of the total for Guiwei and 16.8% for Feizixiao. Since the two cultivars were grown as grafted seedlings, their taproots only grew 50 to 70 cm deep.

Table 2. Biomass of main tissues of Guiwei and Feizixiao lychee cultivars grown in Guangdong, China.

	-------- Guiwei --------		-------- Feizixiao --------	
	Biomass, kg/tree	Percentage, %	Biomass, kg/tree	Percentage, %
Fruit	52.5	27.8	61.5	21.1
Leaf	24.6	12.9	19.7	6.8
Trunk	88.2	46.6	161.0	55.3
Root	24.1	12.7	48.7	16.8
Total	189.4	100	290.9	100

Lychee fruit consists of a pericarp (shell), pulp (fruit flesh) and seed. The shell can be separated by hand into an epicarp (outer layer) and a membranous endocarp (inner layer). Fruit flesh comprised 76% of the total Guiwei fruit weight, which was higher than Feizixiao fruit (70%). Both cultivars had similar weight percentages for the epicarp and seed. However, the endocarp showed a larger difference at 7.3% of the fruit weight for Feizixiao and 3% for Guiwei.

Nutrient Uptake

Large differences in nutrient uptake were recorded in the leaves, trunks and roots of the two lychee tree types, thereby reflecting a large difference between the size of these two trees (**Table 2**). The available information on nutrient accumulation

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; Ca = calcium; Mg = magnesium; S = sulfur; B = boron; Cu = copper; Fe = iron; Mo = molybdenum; Mn = manganese; Zn = zinc; Si = silicon.

in lychee fruits is in fact very limited. This work did find considerable difference in the nutrient uptake for each 50 kg fruit produced by the two cultivars (**Table 3**). While part of these differences might be linked to the differences in yield, the nutrient concentrations within the two fruit varieties were surprisingly similar.

Nutrient Concentration

Irrespective of cultivar, K concentrations in all organs/tissues of the lychee tree were highest amongst nutrients, especially in the fruit, followed by N in leaves, fruit shell (epicarp and endocarp), fruit flesh, and seed (or Ca in the case of the trunk and roots). The Feizixiao variety had similar or higher nutrient concentrations in the trunk and the fruit flesh compared to Guiwei. Low soil Mo content plus variable Mo mobility in plants (depending on plant part and Mo supply) as reported by Jongruaysup et al. (1994) may be responsible for undetectable Mo levels in the trunk and pulp in this study. Because Mo is indispensable for higher plants and plays an important role in metabolism of C, S and N and normal functions of plant hormones (Mendel and Bittner, 2006), it could be a major yield-limiting factor for lychee production in China, especially since Mo is not commonly applied.

The lychee tree has been cultivated in China since 2000 BC. It bears fleshy fruit with a rough outer shell.

Nutrient Distribution

The examination of nutrient partitioning amongst Guiwei tree parts revealed that N, P, K, and Cu were mainly distributed in trunk, leaves and fruit, with Ca being primarily in the trunk; and Mg, S, Fe, Zn, and B were distributed in trunk and leaves, and Mo in the fruit and leaves only. For Feizixiao, the trunk acted as the major sink of nutrients, except for Mo, which was split 41%, 41% and 18% between the leaves, roots and fruit, respectively. It should be noted that almost all Mo stored in the Guiwei tree and nearly two-thirds of the Mo within the Feizixiao tree is removed mechanically by pruning—indicating that Mo application would be most beneficial right after this pruning practice.

Nutrient distribution in fruit showed that most of N, P, K, Mg, S, Cu, and Zn accumulated in the fruit flesh, followed by the outer shell layer, while the inner shell layer had their lowest contents (**Table 4**). Calcium and B, two important components of cell walls, were primarily located in outer shell. It has been reported that B application promotes Ca uptake by the fruit (Wojcik and Wojcik, 2003; Gong et al., 2009), and that foliar Ca spray alone could not significantly prevent fruit cracking (Huang et al., 2008). This does suggest that it might be effective to apply B and Ca together. In Guiwei fruit, 64.5% of the Mo concentration was in outer shell and the remainder was in seed and inner shell layer. In Feizixiao fruit, however, all Mo was accumulated in the seed.

Table 3. Nutrient uptake by different organs of Guiwei and Feizixiao lychee cultivars to produce 50 kg of fruit in Guangdong China.

Nutrient	Fruit	Leaf	Trunk	Root	Total
			Guiwei		
N, g	96	180	127	47	450
P, g	15	11	15	6	46
K, g	169	141	183	52	545
Ca, g	20	97	279	57	453
Mg, g	11	18	24	10	64
S, g	11	22	36	11	81
Fe, mg	334	1,967	3,688	2,514	8,503
Mn, mg	324	3,371	845	209	4,749
Cu, mg	75	57	99	49	280
Zn, mg	173	215	189	95	672
B, mg	112	174	292	115	693
Mo, mg	0.126	0.069	-	-	0.196
			Feizixiao		
N, g	95	134	329	66	624
P, g	16	11	151	10	187
K, g	140	101	653	62	957
Ca, g	17	54	521	86	679
Mg, g	12	12	44	13	80
S, g	11	19	64	19	112
Fe, mg	404	836	8,016	5,369	14,625
Mn, mg	117	650	715	137	1,619
Cu, mg	97	65	194	52	408
Zn, mg	179	272	872	184	1,507
B, mg	114	208	382	139	843
Mo, mg	0.293	0.661	-	0.661	1.615

Not only the concentrations of different nutrients, but also the distribution of the same nutrient in different plant organs/parts varied considerably. For example, N content was higher in leaves and was lower in the fruit flesh regardless of cultivar. Phosphorus was concentrated in the inner shell layer, while the lowest amount of P was found in the trunk of both varieties. Similarly, K content was highest in the fruit flesh, but

Table 4. Nutrient distribution in different fruit tissues of Guiwei and Feizixiao varieties of lychee grown in Guangdong, China.

Nutrient	------ Fruit shell ------ Epicarp (outer), %	Endocarp (inner), %	Fruit flesh, %	Seed, %
		Guiwei		
N	21.4	40.1	28.1	10.4
P	31.5	24.8	31.6	12.1
K	31.0	25.9	33.6	9.5
Ca	4.5	21.3	61.7	12.5
Mg	17.5	28.6	38.0	15.8
S	14.0	27.4	44.6	14.1
Fe	3.9	23.1	43.4	29.6
Mn	6.8	71.0	17.8	4.4
Cu	26.9	20.2	35.3	17.6
Zn	25.8	31.9	28.2	14.1
B	16.2	25.1	42.1	16.6
Mo	64.5	35.5	-	-
		Feizixiao		
N	15.3	21.4	52.8	10.5
P	8.4	5.9	80.3	5.4
K	14.6	10.6	68.3	6.5
Ca	2.6	8.0	76.8	12.7
Mg	14.6	14.6	54.8	16.0
S	9.5	16.5	57.4	16.6
Fe	2.8	5.7	54.8	36.7
Mn	7.2	40.1	44.2	8.5
Cu	23.7	16.0	47.5	12.7
Zn	11.9	18.1	57.9	12.2
B	13.6	24.6	45.3	16.5
Mo	18.2	40.9	0.0	40.9

was lowest in the roots of both cultivars. Calcium was highest in leaves of Guiwei and the trunk of Feizixiao, but only trace amounts of Ca were detected in the fruit flesh of both cultivars. It should be noted that although Ca is commonly regarded as a secondary nutrient for plants, its concentrations in trunk and roots of tree were higher than N concentrations.

Summary

These results build upon known relationships between improved fertilization techniques and stable tree fruit production. Valuable insight was gained into nutrient uptake and storage patterns in lychee, which is vital information to growers as they decide how best to adapt 4R Nutrient Stewardship principles to achieve high quality fruit production.

Acknowledgement

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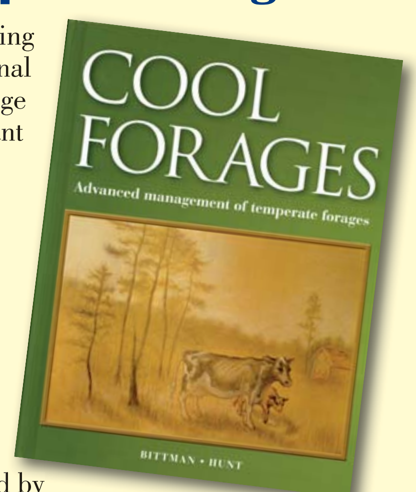
RECOMMENDED READING

Cool Forages: Advanced Management of Temperate Forages



This new publication includes practical explanations of the principles of managing forage crops, including plant nutrition and its effects on both yield and nutritional quality. It comprises 50 chapters of science-based information useful to forage producers in northern temperate climates. Here is a short list of some of the important topics it contains, related to plant nutrition.

- Nitrogen credits from perennial forages
- Description of an on-line soil-crop-nitrogen modeling tool
- Managing phosphorus losses from forage
- Soil testing for forages
- Whole-farm nitrogen budgets
- Manure application timing and placement
- Managing the calcium nutrition of the dry cow in transition

Published in 2013, the book was edited by Shabtai Bittman and Derek Hunt, both scientists with Agriculture and Agri-Food Canada in Agassiz, British Columbia. More than 50 agronomic scientists contributed their input to individual chapters. Published by the Pacific Field Corn Association, a Not-for-Profit Society of farmers and agribusiness. The book can be ordered at http://www.farmwest.com. BC

Potassium in Agriculture: Status and Perspectives

By Christian Zorb, Mehmet Senbayram and Edgar Peiter

A German research group recently published a review paper taking a fresh look at the behavior of K in soil and in plants. A few of their new findings are summarized here.

Potassium in Soils… What is New?

Root Exudates: The ability of plants to utilize non-exchangeable K sources in soil can be important. Various species have been reported to differ in their capacity to use non-exchangeable K. For example, ryegrass and sugar beet are 3 to 6 times more efficient in mobilizing K than wheat and barley. Crop differences in K uptake are in part due to mobilization of non-exchangeable K by root exudates. One group of compounds released by roots is organic acids, including: citric, oxalic, tartaric, and malic acids. Similarly, amino acids detected in root exudates of wheat and sugar beet were found to enhance the release of K from clay minerals.

Soil Bacteria: Some soil microorganisms are able to release K from geologic minerals by excreting organic acids. These organic acids either directly dissolve rock K or chelate the associated silicon (Si), bringing the K into solution. The practicality of adding K-solubilizing microorganisms is now being studied. Little information currently exists on the field application of such methods.

Potassium in Plants

In the agronomic literature, high K concentrations in crops are often classified as "luxury consumption." However, the authors report that high accumulation of K by crops during optimal growing conditions may be considered as an "insurance strategy" to enable plants to better survive sudden environmental stresses.

Photosynthesis and Photosynthates: In contrast to N and P deficiency, K deficiency results in an accumulation of sugars, a consequence of impaired sucrose export from leaves. One reason for this is that sucrose export to the root is reduced in K-deficient plants, caused by a K requirement for the loading of the phloem with sucrose.

Phloem Transport: The translocation of photosynthates from leaves to the roots and fruit generally occurs in the phloem. As the most abundant inorganic cation in the phloem, K has an additional function in counterbalancing mobile anions in the phloem. It is often the dominant counter-ion for nitrate (NO_3^-) in long-distance transport in the xylem

Drought Stress

Potassium is quantitatively the most important component in regulating the internal osmotic pressure and is a main determinant of cell turgor. Adequate turgor pressure is required for cell expansion, so this is especially important for growing plants. For a crop growing in an increasingly dry soil, adjusting osmotic pressure may be accomplished by the synthesis of organic compounds, but this process is very costly to the plant. In contrast, the uptake and storage of increased amounts of K is an energetically 'cheaper' alternative. In the field, an ample K supply will support osmotic adjustment and sustain cell expansion in dry soil conditions.

Abbreviations and Notes: N = nitrogen; P = phosphorus; K = potassium; CO_2 = carbon dioxide.

Reduced crop stress often results in higher quality produce as seen above showing tomato grown with adequate soil K supply (left) versus low soil K (right).

As N is often a limiting nutrient for crops, increased N fertilization requires a further increase in K availability to maintain the plant's water status, particularly in dry conditions. As an osmoticum (i.e., a substance that acts to supplement osmotic pressure in the plant), K also plays a central role in regulating stomatal aperture and limiting water loss. Potassium is required for proper stomatal opening by providing the osmotic driving force for water influx into the guard cell vacuole of the leaf.

There is evidence that a major share of the alleviation of drought stress by K is not only from regulating the stomatal aperture, but due to non-stomatal effects on photosynthesis, CO_2 fixation, primary metabolism, phloem loading, as well as on the osmotic pressure in the sieve tubes and thus the flow rate of photosynthates into the sink organs.

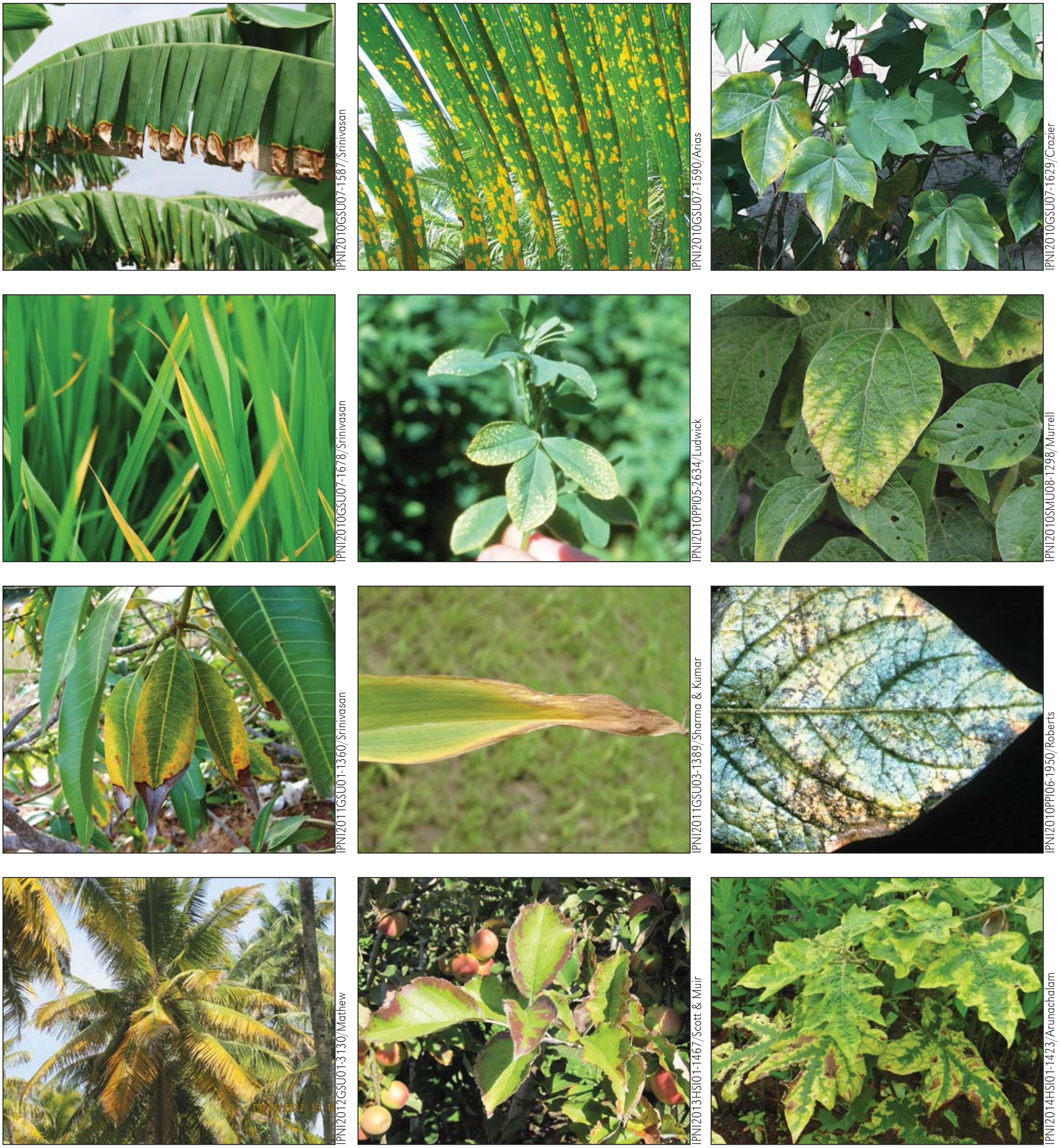
To maintain CO_2 assimilation, the requirement of a sufficient K supply by a crop is higher under drought as compared to well-watered conditions. High soil K supplies may mitigate drought effects, particularly in crops with small root systems, such as many legumes.

In dry soil, root growth is impeded. The smaller root system leads to a further reduction in K uptake. The poorer K supply in dry soils renders a crop less drought resistant, which impairs growth further, again reducing K uptake. This vicious circle may be overcome by optimizing soil or plant factors. To prepare plants for periods of drought stress, K fertilization above the level required for optimum yield under non-stressed conditions may be needed. Since K uptake by roots is hampered under drought, foliar application of K has been suggested, but more research is required. Continued uptake of K from a drying soil can be increased by a deep placement of the K fertilizer, but there is still much to learn about the efficacy of this practice.

Potassium deficiencies are appearing in regions where minimum or no-till cultivation practices dictate that fertilizer be applied to the soil surface. In these situations, applied K accumulates at the uppermost soil layers, which becomes inaccessible to roots during dry periods. Furthermore, soil K concentrations are decreasing in many parts of the world due to a lack of adequate K fertilization.

High Light Stress

In K-deficient plants, CO_2 assimilation is impaired due to



Potassium deficiency symptoms in selected crops (left to right: top row) banana, oil palm, cotton; (second row) rice, alfalfa, soybean; (third row) mango, corn, potato; (bottom row) coconut, apple, eggplant. Source: IPNI Image Collection of Crop Nutrient Deficiency Symptoms, http://ipni.info/nutrientimagecollection.

suboptimal activation of enzymes, inefficient phloem loading and transport, and a decreased stomatal aperture. High light intensity puts an extra strain on these processes because of the excessive energy input in the form of excited electrons. Accordingly, K-deficient plants are more prone to high light damage.

Cold Stress and Frost

With decreasing temperature, enzymatic processes and transporters in the plant are slowed down. Inhibition of these processes causes an enhanced generation of damaging reactive oxygen species (ROS) because the incoming light energy cannot be properly funneled into assimilatory processes, but is instead transferred onto oxygen (O_2). A high K supply is believed to reduce the ROS load of cold-stressed plants.

There is evidence that K has further beneficial roles in freezing stress. Freezing the internal water within a plant causes severe damage. An increased accumulation of K increased the symplastic (inside the cell plasma membrane) osmotic pressure, thereby limiting freeze-induced dehydration. For example, frost damage is often ameliorated by high K fertilization, such as in potato.

Optimized K fertilization is crucial to maximize plant response. There are many advances yet to be made in K fertilization, understanding K behavior in soils, and in improving plant utilization of K. BC

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Further information and detailed scientific references are available in the original in J. Plant Physiol. paper available online, October 17, 2013 http://dx.doi.org/10.1016/j.jplph.2013.08.008

Fertilizer Industry Round Table Recognition Award Deadline is June 30

Fertilizer Industry Round Table

Criteria

1) The award recognizes outstanding achievements in research, extension and/or education that centers on fertilizer technology and associated benefits to agricultural productivity and sustainability.
2) Applicant will be judged based on research originality, quality and practical application as demonstrated by concrete results, letters of recommendation, dissemination of findings, contribution to sustainability, and po tential for international application.
3) Applicant must be a resident of Canada or the United States.

Application Procedures

1) Electronic copy of three letters of support. If a student, one should be from the major professor.
2) A description of the focus of the research presented to be evaluated on originality, scope, innovation and potential application.
3) Award recipients are not eligible for more than one award.
4) Priority will be given to those who support the mission of the Fertilizer Industry Round Table (FIRT).
5) Questions and application materials should be directed in electronic form to: DMessick@sulphurinstitute.org.

Selection Process - A panel of three individuals will select the award winner. The panel will consist of representatives from academia, industry and an environmental-focused entity.

Award - US$2,500 and travel to FIRT's annual conference.

Conversion Factors for U.S. System and Metric

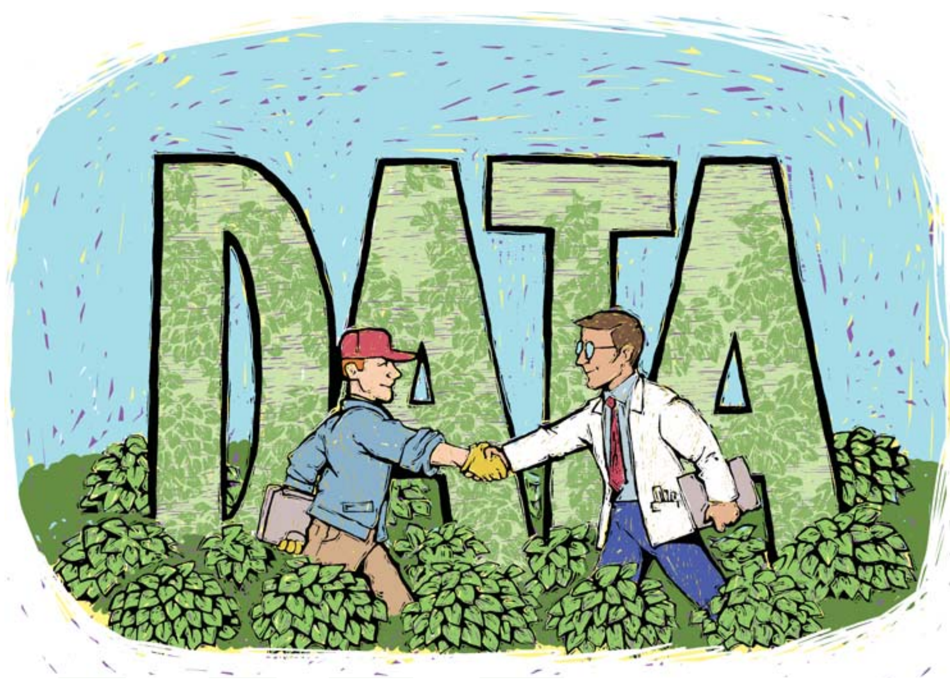
Because of the diverse readership of *Better Crops with Plant Food*, units of measure are given in U.S. system standards in some articles and in metric units in others…depending on the method commonly used in the region where the information originates. For example, an article reporting on corn yields in Illinois would use units of pounds per acre (lb/A) for fertilizer rates and bushels (bu) for yields; an article on rice production in Southeast Asia would use kilograms (kg), hectares (ha), and other metric units.

Several factors are available to quickly convert units from either system to units more familiar to individual readers. Following are some examples which will be useful in relation to various articles in this issue of *Better Crops with Plant Food*.

To convert Col. 1 into Col. 2, multiply by:	Column 1	Column 2	To convert Col. 2 into Col. 1, multiply by:
	Length		
0.621	kilometer, km	mile, mi	1.609
1.094	meter, m	yard, yd	0.914
0.394	centimeter, cm	inch, in.	2.54
	Area		
2.471	hectare, ha	acre, A	0.405
	Volume		
1.057	liter, L	quart (liquid), qt	0.946
	Mass		
1.102	tonne[1] (metric, 1,000 kg)	short ton (U.S. 2,000 lb)	0.9072
0.035	gram, g	ounce	28.35
	Yield or Rate		
0.446	tonne/ha	ton/A	2.242
0.891	kg/ha	lb/A	1.12
0.0159	kg/ha	bu/A, corn (grain)	62.7
0.0149	kg/ha	bu/A, wheat or soybeans	67.2

[1]The spelling as "tonne" indicates metric ton (1,000 kg). Spelling as "ton" indicates the U.S. short ton (2,000 lb). When used as a unit of measure, tonne or ton may be abbreviated, as in 9 t/ha. A metric expression assumes t=tonne; a U.S. expression assumes t=ton.

Data: Landfill or Legacy



If you are reading this back cover, data is likely a significant part of your life. If you do science for a living, your job is to generate meaningful data that offer insight into the perplexing problems of the day. If you are a user of science - CCA, grower, service provider, etc., the products created from scientific data form the principles upon which you make informed decisions or offer informed advice. Indeed, it seems data is critically important to agronomy and perhaps especially important to the discipline of soil fertility. So, the question I pose on this back cover that closes another informative set of data-based scientific articles, is why do we treat data like just another item on a convoluted voyage to the landfill when in fact it can become our legacy?

Data stewardship is a relatively new term to most of us, but I hope it becomes a fundamental element in the lexicon of agronomy. It involves viewing data, and its supportive metadata (data on how the data were collected or the circumstances that created it), as the primary products of scientific endeavor and as such deserving of careful standardization and preservation. With proper care, high quality data sets grow in value with time and with aggregation (enabled by open access). It takes a substantial investment to create such sets, but experience demonstrates that it's a sound investment with an amazing return. This is not a concept relevant only to the professional scientist. It pertains just as well to farms where data can be viewed as another valued product of the farm and the principles discussed above are just as important. Precision ag has taken us a long way down this path, but the journey has just begun.

The North American fertilizer industry, through the creation of the 4R Research Fund, has made a commitment to a step change in data stewardship in agronomic science via two significant actions. The first projects it funded are all systematic reviews with meta-analyses that will create datasets from published scientific literature to address questions about 4R impacts. The second action was to require that data generated by all funded new projects become part of an open-access data repository that will preserve the data to not only answer today's questions, but those of the future as well.

What about your data? Is it on the way to the landfill or to becoming part of your legacy?

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

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