# BETTER CROPS WITH PLANT FOOD

A Publication of the International Plant Nutrition Institute (IPNI)

2015 Number 3

## NWatch™ On-Farm Research Improves Decision and Policy Making for Nitrogen Use

### In This Issue...



IPNI

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# BETTER CROPS
## WITH PLANT FOOD

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


# IPNI Annual Program Report is Now Available

IPNI has released its annual Program Report for 2015 focused on our *Mission with Metrics*.

Our stated mission is to develop and promote scientific information about the responsible management of plant nutrition for the benefit of the human family. Our four strategic goals are:

1. Leadership on global plant nutrition issues through collaboration with others.
2. Facilitation of research.
3. Enabling education on sustainable use of plant nutrients.
4. Supporting our members in their activities related to responsible nutrient use.

These goals were the foundation for the strategic plan we developed when IPNI was first established and continue to be relevant today.

Last year, IPNI put in place a global tactical plan that operates under the guidance of our four strategic goals, and recognizes that 4R Nutrient Stewardship is central to our mission. Our global tactical plan identifies five needs:

1. 4R Nutrient Stewardship must become globally adopted as the scientific basis for sustainability.
2. Nutrient education is inadequate for current and future agronomists.
3. Better fertilizer recommendations are needed to boost productivity, economic returns, and environmental stewardship.
4. Yield gaps must be identified and closed to provide a sustainable food supply.
5. Agricultural sustainability is only maintained by proper nutrient management.

IPNI had identified a short list of key responses for each of these five needs.

With needs and responses identified, we must address metrics. Metrics can measure our performance, our success, and our impact. One of the challenges we face in an organization like ours is to identify meaningful performance metrics.

Some things are easy to track, like communication activities and projects. Last year our scientists made 277 presentations to audiences exceeding 30,000 and we published 112 scientific publications and more than 100 other media pieces. And, we supported 160 research projects in 25 countries. Such metrics show activity and demonstrate we were busy, but they do not reflect the impact of our programs. How these activities influence or change behavior is more challenging to measure.

Quantifying the adoption of 4Rs and the impact their implementation has on the environment is a work in progress. In agricultural systems, results from implementing a change in management can be seen that crop year, such as a yield response to a better fertilizer recommendation. But an improvement in nutrient concentration in groundwater may take years to show up following implementation of a 4R system. Biological systems and nutrient cycles are slow to change.

Achieving our mission is a long-term endeavor. It requires a dedicated, focused staff and the continuing support of our members. We appreciate their vision for the fertilizer industry and recognition that scientific support is essential for sound and sustainable nutrient management. We are privileged to work closely with our members in advancing our mission.

Our annual report will demonstrate actions and metrics related to our responses to the needs identified in our Global Tactical Plan. This report is available from the IPNI website: http:// www.ipni.net/programreport.

Terry Roberts
President, IPNI

# Nitrogen Management in Illinois Intensifies as State Implements Nutrient Loss Reduction Strategy

By Jean Payne and Emerson Nafziger

**A N management program named N-WATCH™** is helping farmers and regulators track changes in soil N concentrations during the year. This on-farm research is leading to better management decisions and improved engagement with policy makers.

Illinois is an intensively tile-drained state with an estimated 11 million sub-surface drained acres that produce high-yielding corn. As farmers invested in additional tile drainage in recent years when commodity prices were high, they improved production on Illinois soils but also created a new challenge in terms of managing N loss to water.

Illinois' newly implemented Nutrient Loss Reduction Strategy estimates that Illinois contributes 7% of the water flow to the Gulf of Mexico, but 20% of the N load to the Gulf—approximately 410 million pounds of N (IL EPA, 2014). The nutrient strategy estimates that tile drainage, which exists mainly in the upper two-thirds of the state's geography, is the largest contributor to N loss, and that agriculture is responsible for 80% of the state's overall N load to rivers, streams and lakes. This is a serious challenge for Illinois agriculture, but one that has been met with a new investment in research that focuses on N management in intensively tile-drained systems.

The Illinois Nutrient Research & Education Council (NREC) collects 75 cents per ton on nearly 4.5 million tons of plant nutrients sold annually in Illinois. A significant portion of these funds is directed at determining how agricultural retailers and farmers can use voluntary approaches to better manage N to reduce losses and enhance crop yields. If this voluntary system fails to make progress in reducing losses, nutrient regulation in Illinois becomes a real probability.

One of the NREC-funded programs directed at N management is N-WATCH™; a management tool that involves sampling soils to depths of 0 to 1 ft. and 1 to 2 ft. at a minimum of four times: 1) at application (fall or spring), 2) in the spring, 3) during the summer, and 4) after crop harvest. Samples are analyzed for ammonium and nitrate, which can be tracked over time, under various environmental conditions. While soil N measured as nitrate or ammonium reflects N from applied fertilizer, it also reflects contributions from N in manure (current or recent) and also N mineralized from soil organic matter. These non-fertilizer sources of available N can be substantial—and difficult to predict—in manured soils and in soils with more than 3 or 4 % organic matter.

N-WATCH™ is not a N recommendation system, but rather a soil N data collection and outreach tool that provides a new level of information for farmers to consider when determining or modifying their N application programs. The idea of tracking N movement in the soil originated during the drought of 2012, and was put into place to determine how much N remained in the soil following low yields or crop failure that year. We were particularly interested in assessing the environmental risk posed by leftover soil inorganic N and how agriculture might be ready to respond if $NO_3^-$-N losses were significant in the spring of 2013.

**Abbreviations and notes: N = nitrogen; $NO_3^-$-N = nitrate nitrogen.**


**N-Watch™** on-farm field research site.

N-WATCH™ assists the industry and producers in making N management decisions, but equally important is the opportunity it creates for agriculture to provide leadership on N issues and to develop practical nutrient policy. As an example, sampling over 150 N-WATCH™ sites in the fall of 2012 showed that on average, 140 lbs of $NO_3^-$-N per acre was present in the top 2 ft. of soil. These data made it clear that $NO_3^-$-N was left over from the 2012 cropping season; fall-applied N was nearly all in the ammonium form when fields were sampled. This also meant that any potential $NO_3^-$-N losses from tile lines in the early spring would likely be coming from leftover N, not from fall-applied N.

The agricultural industry shared their analysis with the University of Illinois, Illinois Environmental Protection Agency, and water supply officials to prepare them for the possibility of high $NO_3^-$-N levels in surface water supplies in 2013. This revelation was met at first with trepidation, but then with appreciation as it helped officials prepare for the possibility of elevated $NO_3^-$-N (i.e., above 10 mg/L $NO_3^-$-N) in their water supplies. This turned into reality, when under high precipitation and tile line flows in late winter and early spring of 2013, surface water $NO_3^-$-N concentrations rose to some of the highest levels of recent years. This transparency by agricultural leaders, combined with credible information

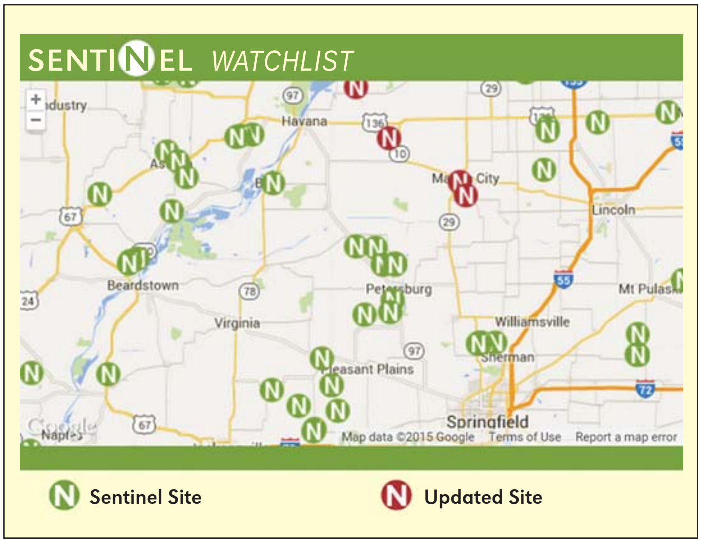


**Figure 1.** View of N-Watch™ website designed to allow public monitoring of soil ammonium- and nitrate-N levels. http://www.illinoiscbmp.org/Nitrogen-Management/N-Watch/

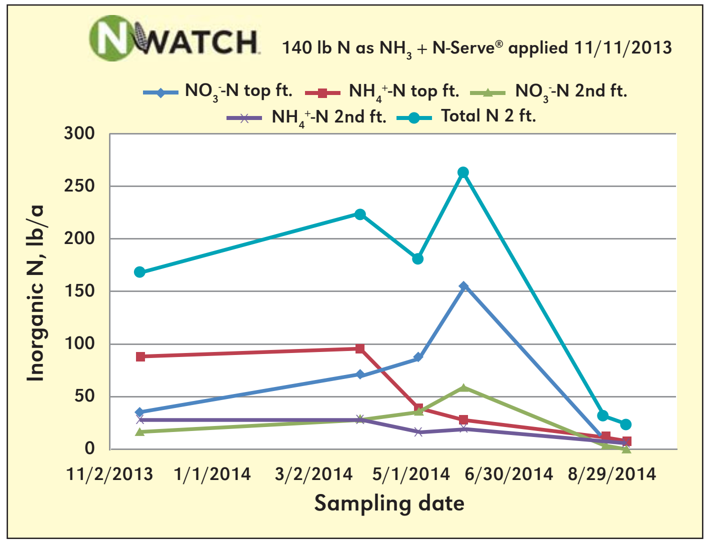


**Figure 2.** Soil profile nitrate ($NO_3^-$) and ammonium ($NH_4^+$) trends during the 2014 growing season (November to August). N-Serve® is the trade name for Nitrapyrin - a nitrification inhibitor.

provided by N-WATCH™ fostered a productive working relationship between agriculture leaders, water providers and policy makers that has continued through the development of the state's nutrient loss reduction strategy.

Two years later, N-WATCH™ continues to provide valuable information on soil ammonium and nitrate concentrations through the season across several hundred sites. In 2015, the Illinois Council on Best Management Practices (a consortium of Illinois agricultural organizations) hosted an N-WATCH™ "sentinel" website as an educational tool, to allow anyone interested, a glimpse into soil N levels at anonymous sites (**Figure 1**). Additionally, the industry shares analysis of N-WATCH™ findings at conferences with retailers and farmers to educate on N management and pique interest in the program (**Figure 2** is an example). A new database management system called N-WATCH™ Online allows for participants to review results in a timely manner and share findings with the participating farmers. Output from a current 2015 N-WATCH™ site in central Illinois illustrates the impact of record rainfall in June 2015 (**Figure 3**).

The N-WATCH™ program has also provided impetus for new research initiatives in Illinois on soil N and corn yield responses, designed to show how various 4R application practices (source, rate, time, place) influence plant-available N under varying soil, crop, and weather conditions. Dr. Emerson Nafziger and colleagues at the University of Illinois initiated a project in 2015 entitled "Tracking Soil Nitrogen Loss and Availability." This work is designed to combine some of the data collected under the N-WATCH™ project with more frequent sampling data from trials comparing different N forms

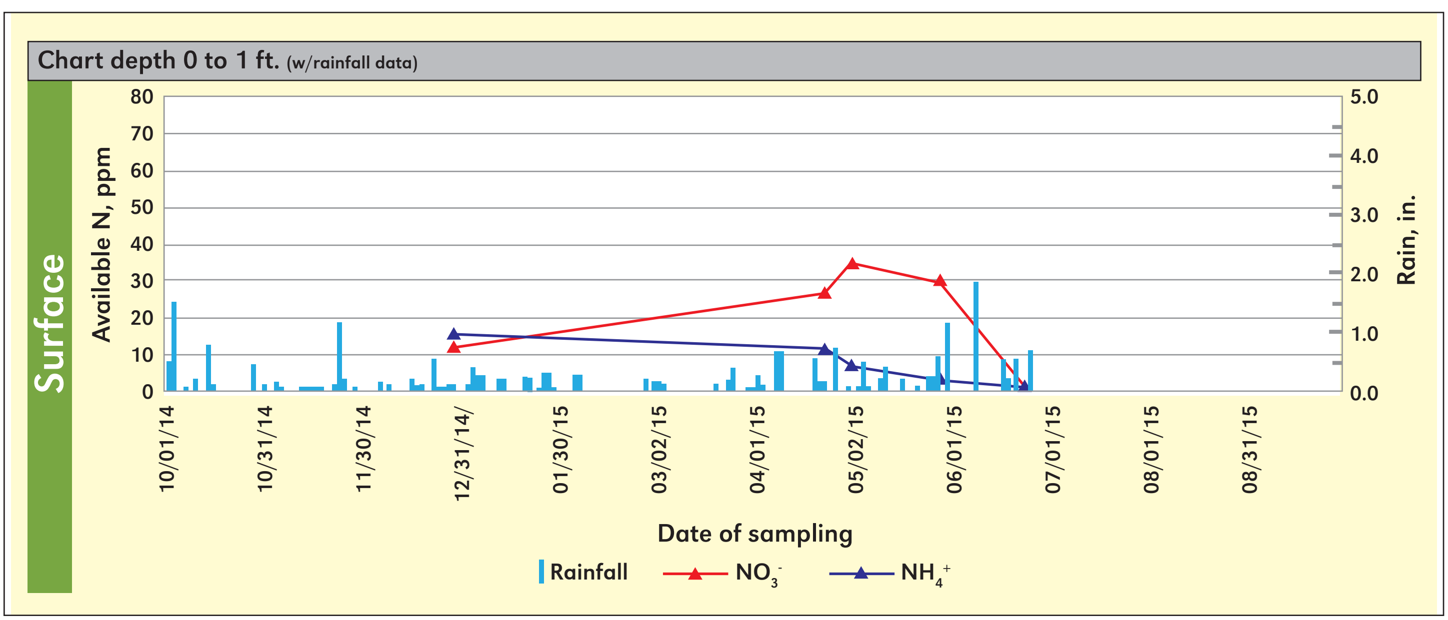


**Figure 3.** Field site data display from an N-WATCH™ site in central Illinois illustrating the impact of record rainfall, during June 2015, on available soil N (ammonium-N and nitrate-N) concentrations within the 0 to 1 ft. depth.

and timings of application. Results will be used both to report current soil ammonium and nitrate concentrations throughout the spring in order to advise on the need to apply supplemental N; and also to develop a model, to predict current available soil N, based on weather following applications of different times and forms of fertilizer N.

## Summary

Improving N management while reducing N loss in Illinois will be neither quick nor easy. Getting enough N to the crop under a wide range of weather conditions will always be a challenge, and new technologies that might help do this bring added costs, the need for additional learning, along with difficult-to-assess capabilities of decreasing uncertainty related to crop response and N loss. However, we strongly believe that everyone—producers, officials, agricultural input suppliers, environmental groups, and the general public—are best served by programs that integrate findings and practices in a transparent fashion in order to bring everyone along on the ride. BC

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*The mention of any trade name does not necessarily imply any endorsement.*

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IPNI ANNOUNCEMENTS

# IPNI Board of Directors Elects New Officers

Two new officers of the Board of Directors of the International Plant Nutrition Institute (IPNI) were elected in May 2015. The election took place at the IPNI Board meeting held in Istanbul, Turkey, in conjunction with the Annual Conference of the International Fertilizer Industry Association (IFA).

Mr. Oleg Petrov, Director of Sales and Marketing Uralkali, Moscow, Russia, was elected Vice Chairman. Mr. Petrov replaces Mr. Jim Prokopanko, CEO of Mosaic, Plymouth, Minneapolis, USA, who is retiring later this year, and who was recognized for outstanding leadership and service in his role.

Mr. Tony Will, CEO of CF Industries Holdings, Inc., Deerfield, Illinois, USA, was elected Chair of the Finance Committee. Dr. Mostafa Terrab, Chairman and CEO, OCP Group, Morocco, continues as Chairman of the IPNI Board.

**Dr. Mostafa Terrab**
Chairman
of the IPNI Board

**Mr. Oleg Petrov**
Vice Chair
of the IPNI Board

**Mr. Tony Will**
Chair of the
Finance Committee

"We look forward to continued great leadership on our Board and working committees," said Dr. Terry Roberts, President IPNI. "We will miss Jim and the many contributions he has made to our Institute, but are confident in the new leaders and the direction they will provide to IPNI going forward." BC

# IPNI Appoints Phosphorus Program Director

The International Plant Nutrition Institute (IPNI) has appointed Dr. Tom Bruulsema as its Phosphorus Program Director.

"This change in focus reflects a need to devote greater attention to phosphorus, its role in global food security, and its potential for unintended environmental impacts," explained IPNI President Dr. Terry Roberts. "Tom has been directing IPNI programs in the Northeast for 21 years and will continue his involvement and leadership on 4R nutrient stewardship and sustainability issues."

All IPNI scientists' activities include agronomic programs that address phosphorus, nitrogen, potassium and other plant nutrients, and 4R Nutrient Stewardship is a strategic component of the Institute's regional and global tactical plans. Having a Phosphorus Program Director will provide a point person to lead the Institute's ongoing efforts in ensuring phosphorus is used effectively and efficiently.

Dr. Bruulsema has been recognized as a Fellow of the American Society of Agronomy, the Soil Science Society of America, and the Canadian Society of Agronomy. He will continue to be based in Guelph, Ontario, Canada. BC

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**Dr. Tom Bruulsema**
Phosphorus Program Director

# Co-granulated Elemental Sulfur/Sulfate Fertilizers and Their Role in Crop Nutrition

By Mike J. McLaughlin, Fien Degryse, Rodrigo C. da Silva, and Roslyn Baird

**The effectiveness of S-enhanced ammoniated phosphate fertilizers,** with both fast and slow release forms of S, differs based on the growing environment.

**The presence of elemental S can be advantageous** in environments at risk for leaching of sulfate.

**Sulfate-S performs best in environments with less risk of loss,** but products co-granulated with a suitable size of elemental S can be equally effective.


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**Sulfur-enhanced fertilizers** can be an efficient option to deliver sulfur to crops like canola, which can be grown across a variety of climates and soils around the world.

Sulfur (S) is one of the 17 elements essential for plant growth and the fourth after N, P and K in terms of amounts required by crops. It plays a key role in plant nutrition through its activity in photosynthesis and in the synthesis of amino acids and proteins. Sulfur shares a similar behavior to N in soils and plants—it is sensitive to leaching, can be immobilized into organic matter, and is present in different oxidation states. Reduced forms of S include elemental S (ES), iron sulfide minerals present in waterlogged (e.g., paddy rice) soils, and S bound to carbon present in soil organic matter (SOM). Oxidized forms of S include sulfate minerals (e.g., gypsum), sulfate-esters in SOM and sulfate-S present in the soil solution.

Plants take up S from soils predominantly as sulfate via the soil solution. Hence, like N, the availability of S in soils is also affected by mineralization or immobilization reactions with SOM. Another similarity with N is that the oxidized form of S (sulfate) is highly mobile in soils (like nitrate) and can be easily lost from soils by leaching in higher rainfall environments, hence potentially reducing the efficiency of applied S fertilizer.

**Abbreviations and notes: N = nitrogen, P = phosphorus; K = potassium; S = sulfur; ES = elemental sulfur.**

Sulfur fertilizers are predominantly either sulfate-based (e.g., ammonium sulfate, gypsum, potassium sulfate) or based on ES [e.g., ES pastilles or ammoniated/calcium-based phosphatic fertilizers containing ES such as S-enhanced triple superphosphate (TSP), monoammonium phosphate (MAP) or diammonium phosphate (DAP)]. Sulfate-based fertilizers provide a source of S (sulfate) that is immediately available for crop uptake but these fertilizers contain relatively low S contents (<25% S) so higher application rates are needed and transport costs are relatively high. Pure ES fertilizers have the advantage that they are the most concentrated form of S (>90% S) and thus application rates and transport costs are lower. However, to become available for plant uptake, ES must first be oxidized in soil to sulfate and hence the supply of S to plants is slower than for sulfate. Fertilizers that combine these two forms of S can provide both a fast and a slow release source of S for crop nutrition. But how quickly is the S released from the ES in these products?

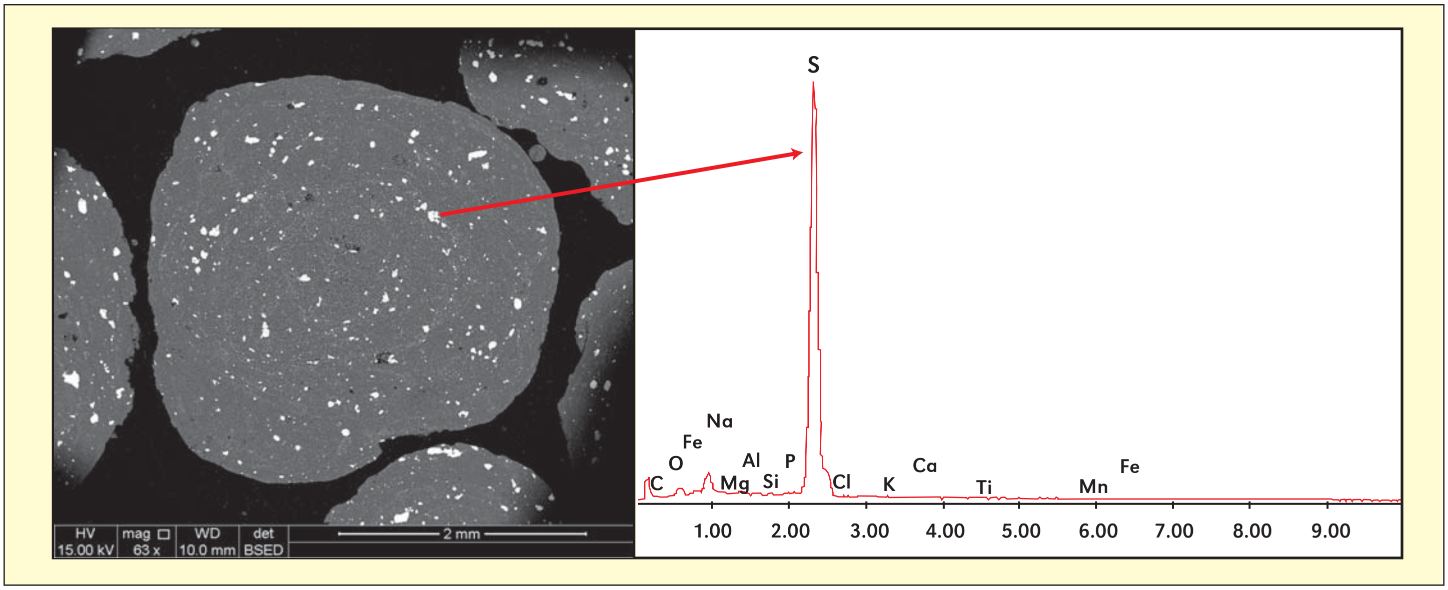


**Figure 1.** Typical ES/sulfate fertilizer co-granulated with ammonium phosphate and the x-ray analysis of the bright particles in the granule confirming the particles are ES.

Oxidation of ES fertilizers in soil has been studied for decades, and it is well known that the particle size of the ES fertilizer plays a major role in controlling the rate of oxidation and release of sulfate. Research has shown smaller particles oxidize faster because the surface area to volume ratio of a particle increases as the diameter of the particle decreases.

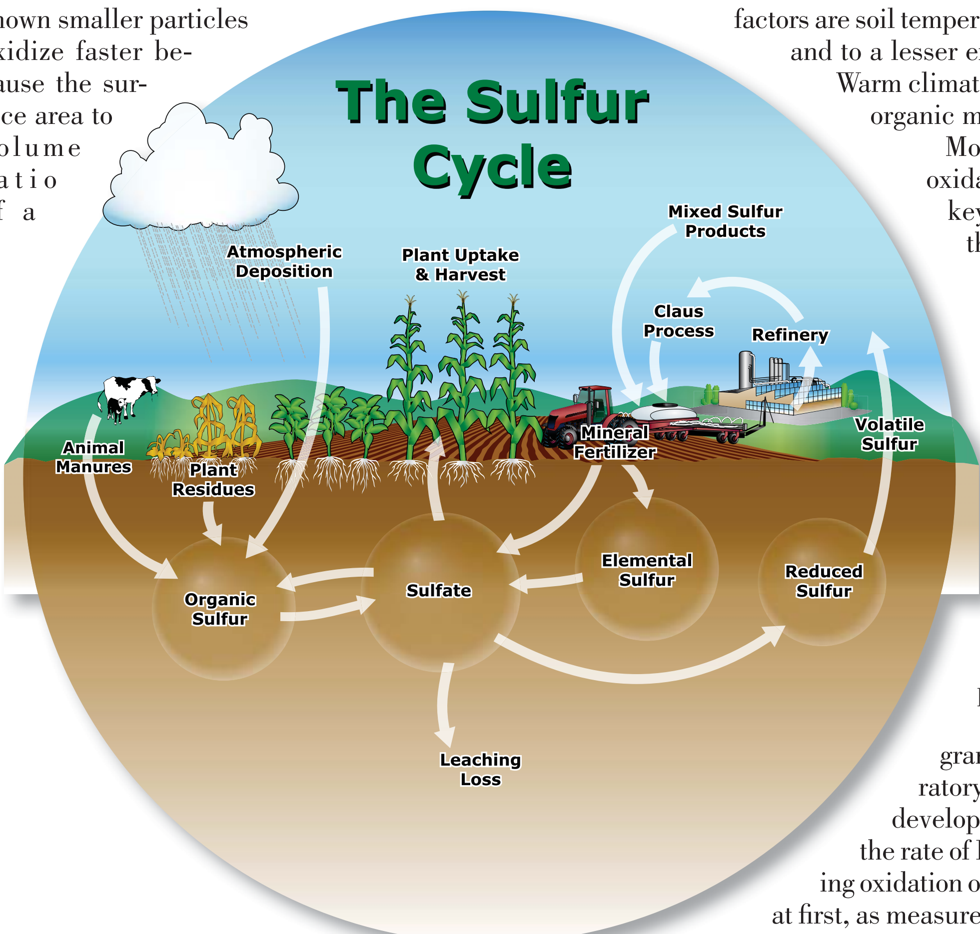


**Figure 2.** Fate of fertilizer S, added as either elemental S or sulfate in soil. The major pathways of loss for sulfate from soil are removal with harvested crop products, immobilization in soil organic matter (Organic S), and leaching.

Oxidation of ES is carried out by a wide range of soil microorganisms and therefore is affected by factors that affect microbial abundance and activity in soils. The most important factors are soil temperature and soil pH, but organic C content and to a lesser extent soil water status also play a role. Warm climates with non-acidic soils that are rich in organic matter will oxidize ES the fastest.

Models have been developed to predict oxidation of ES in soil based on the above key factors controlling oxidation assuming the ES is well-mixed throughout the soil. However, this is rarely the case and ES is usually added to soil in granules or prills/pastilles consisting solely of ES with a binder or dispersant, or coated or co-granulated with other macronutrient fertilizers. Based on greenhouse experiments, it has been observed that ES in these products, despite having small ES particles embedded in the granule (**Figure 1**), oxidizes much slower than ES particles of the same size mixed throughout the soil (Friesen, 1996) with pure ES granules/prills being the slowest.

The oxidation of ES in these co-granulated products was examined in laboratory, greenhouse and field experiments to develop a better understanding of what controls the rate of ES oxidation in these products. Measuring oxidation of ES fertilizer in soils might seem simple at first, as measurement of sulfate produced is a relatively simple chemical procedure. However, sulfate released from ES fertilizers can be leached, taken up by plants, or incorporated into SOM (**Figure 2**), so the increase in sulfate-S may underestimate ES oxidation.

The oxidation of ES in three fertilizers was measured in

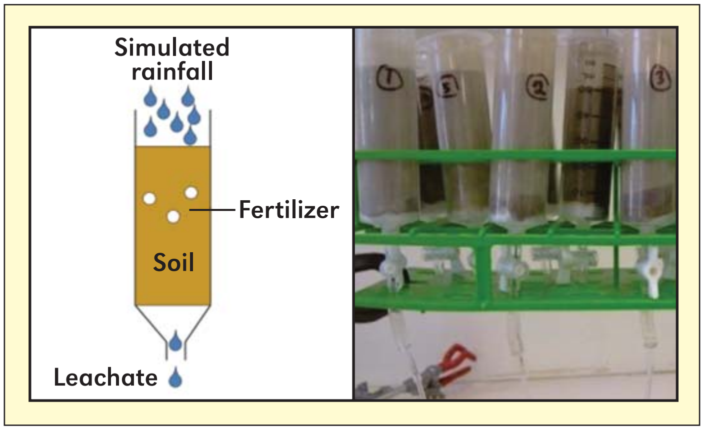


**Figure 3.** Picture of leaching procedure to measure oxidation of ES in soil (left: schematic diagram; right: columns)

laboratory experiments by regularly leaching sulfate out of the soil to minimize immobilization in SOM (**Figure 3**) and by measuring ES remaining at the end of the experiment (by solvent extraction) to check the mass balance of S.

Over 12 months, the oxidation of ES prills was slow, oxidation in co-granulated ES/MAP/sulfate fertilizers was faster, and the fastest oxidation was observed when ES was uniformly mixed throughout the soil (**Figure 4**). By contrast, nearly all added S was removed during the first leaching event for the ammonium sulfate treatment (Degryse et al. 2015).

The reason oxidation of ES is slower in co-granulated products (for a given particle size of ES) is that the surface of ES in contact with the soil (and soil organisms) is lower when the ES is co-granulated than when ES particles of the same size are mixed throughout the soil. After the soluble nutrients (N, P) in the granule have dissolved and diffused from the granule, a 'collapsed cavity' with ES remains. Further oxidation will depend on the surface of ES in contact with the soil, the granule size, the ES content of the fertilizer, and the diameter of the ES particles (**Figure 5**). Based on these geometrical considerations, we were able to model the reduction in oxidation rate for co-granulated ES fertilizers compared to ES particles mixed throughout soil.

The much slower oxidation for ES pastilles than for S-enhanced MAP fertilizers was confirmed in a pot experiment, in which the S availability to plants was not different from the MAP control. However, the availability of S for the co-granulated fertilizer was higher than for ammonium sulfate in a second crop (**Figure 6**). The low S uptake for the ES pastilles treatment is due to slow oxidation and the relatively low uptake for the AS treatment is due to uptake by the first crop and immobilization in SOM.

Crop recovery of S from the sulfate-S and ES in co-granulated products containing both forms of S was measured by labeling with an enriched stable isotope—$^{34}$S. Labeled $^{34}$S products were manufactured where either the ES or the sulfate-S was labeled and used in field trials at various locations in North and South America.

As expected, where sulfate leaching is a potential risk after fertilization (e.g., fall applications in North America) the ES in the fertilizer was a more effective source than the sulfate-S (**Figure 7**). On the other hand, where sulfate leaching was not significant, the sulfate-S source had the highest initial avail-

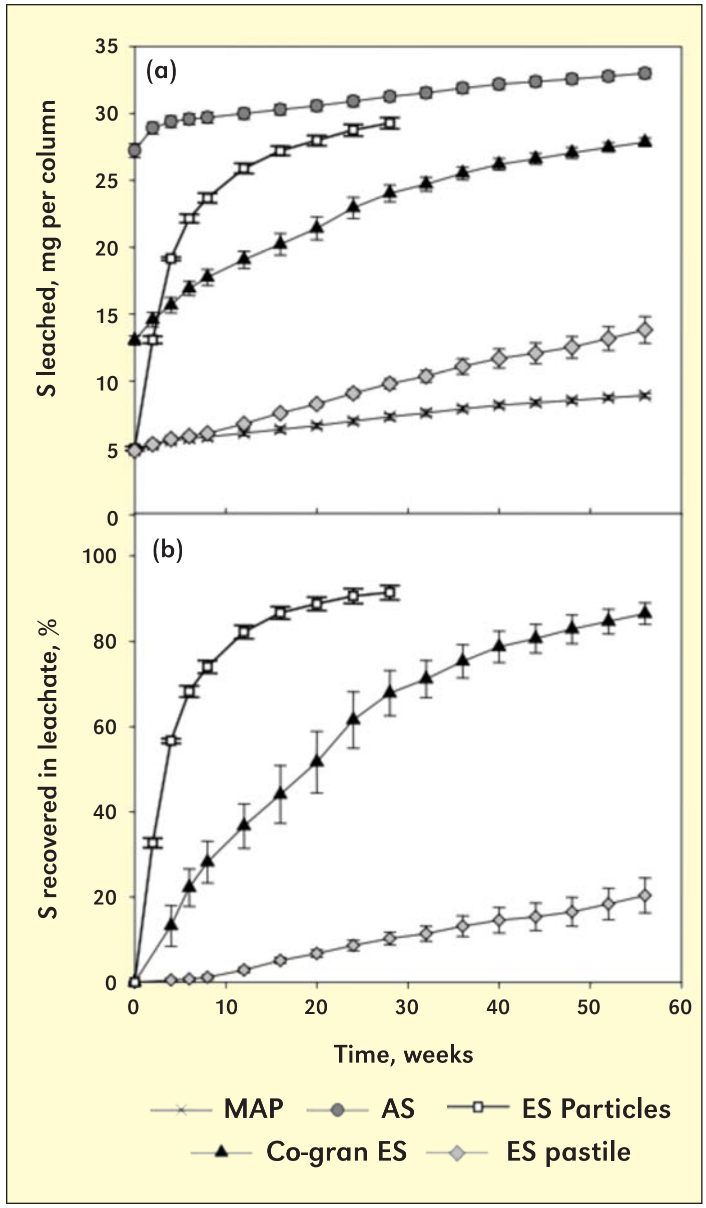


**Figure 4.** (a) Release of sulfate-S in the leachates and (b) recovery of sulfate-S derived from the oxidation of ES. The soil (pH 6.3, 73% sand, 2.8% organic carbon) was incubated with MAP or various S-containing fertilizers (24 mg S added) at 25°C over 12 months and leached at regular intervals (Degryse et al., 2015). MAP = monoammonium phosphate; AS = ammonium sulfate; ES = elemental S particles (diameter of 65 μm) mixed through soil; Co-gran = elemental S/sulfate in MAP; ES pastille = elemental S pastille with 90% ES and 10% bentonite. Error bars equal standard errors of four replicates.

ability to the crop and ES was a slower release source later in the season and in subsequent seasons. As stated previously, speed of oxidation was primarily controlled by temperature and soil pH.

## Summary

A model is now being developed to predict the oxidation of ES in co-granulated products based on particle size of the ES, granule diameter, ES content of the fertilizer, and the environmental variables that control oxidation rate (principally

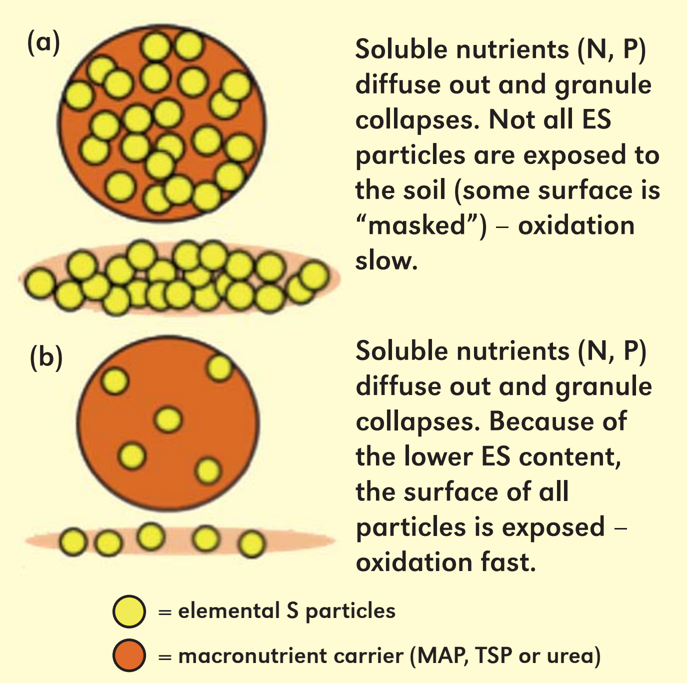


**Figure 5.** Schematic of dissolution of granulated fertilizers containing ES for a granule with (a) high or (b) low ES content.

soil temperature and soil pH). After validation, this model should allow the tailoring of fertilizer S formulation to meet crop demand in various environments and growing conditions.


## Acknowledgement

The authors would like to acknowledge the support from The Mosaic Company LLC.


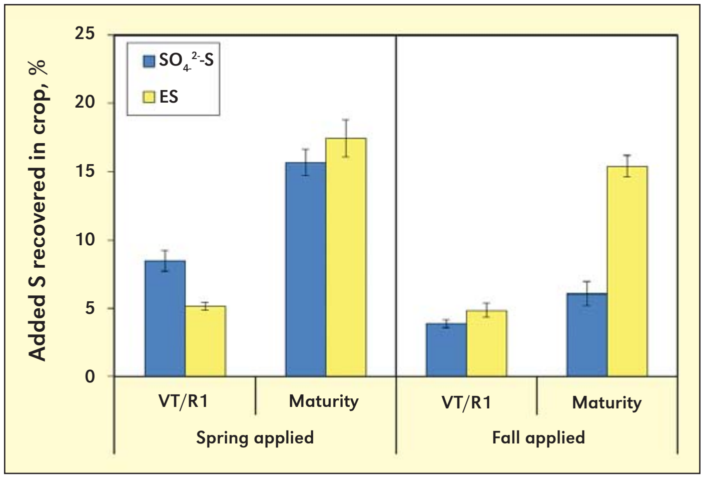


**Figure 7.** The percentage of added S recovered in corn (above-ground biomass) at tasseling and maturity for the sulfate-S ($SO_4^{2-}$-S) or elemental S (ES) in S-enhanced MAP fertilizer as measured through stable isotope $^{34}$S labeling for spring- and fall-applied fertilizers (Trial in Illinois, 2013-2014). Error bars represent standard errors of four replicates.


*Prof. McLaughlin (e-mail: michael.mclaughlin@adelaide.edu.au), Dr. Degryse, Dr. da Silva, and Ms. Baird are with the Fertiliser Technology Research Centre, The University of Adelaide, Australia (www.adelaide.edu.au/fertiliser/).*


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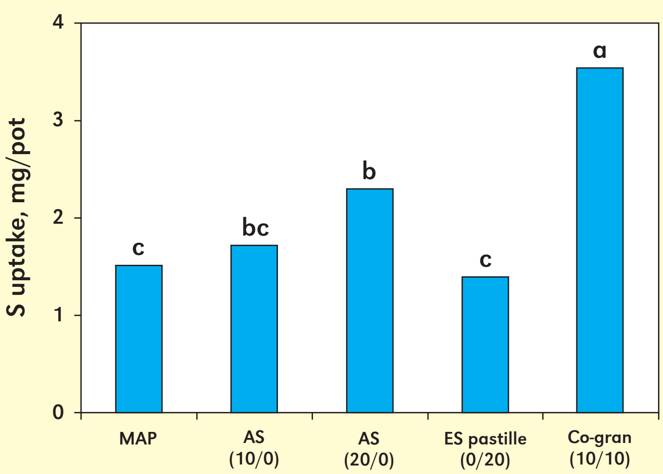


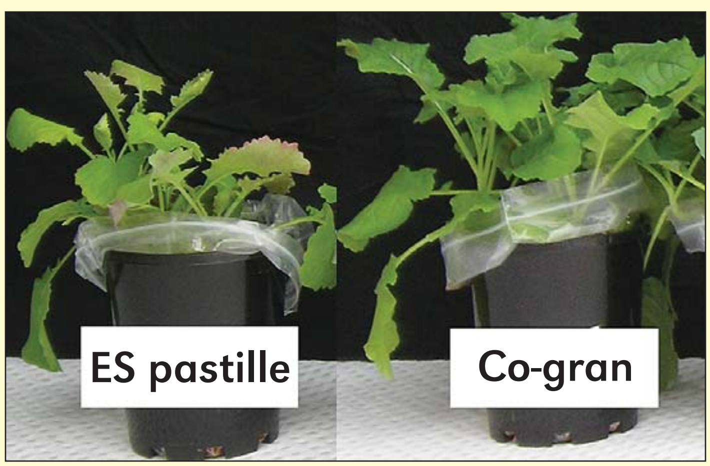


**Figure 6.** **Left -** Sulfur uptake by a second canola crop grown in pots. Fertilizer treatments were monoammonium phosphate (MAP) only (control), ammonium sulfate (AS), ES pastilles or S-enhanced MAP fertilizer (numbers in brackets are amount of sulfate-S/ES added with the fertilizer in mg per kg soil). Different letters above the bars indicate significant ($p < 0.05$) differences between treatments. **Right -** Canola grown with S-enhanced MAP fertilizer (ES pastilles on left side; Co-gran on right).

# Sulfur Nutrition of Oil Palm in Indonesia— The Neglected Macronutrient

By Joska Gerendás, Christopher Donough, Thomas Oberthür, Rahmadsyah, Gatot Abdurrohim, Kooseni Indrasuara, Ahmad Lubis, Tenri Dolong, and Miles Fisher

**Little attention has been paid to the S nutrition of oil palm,** despite a trend towards using fertilizers that contain no S.

**Data show S concentrations can be far below** the established critical value of 0.20%.

**The established critical S concentration should be reduced** to 0.15% based on a critical N concentration of 2.3% and an S:N ratio of 15.

There has been little research on S in oil palm compared with other plant macronutrients. This is because until recently most nutrition research on oil palm was done in Malaysia, where ammonium sulfate [$(NH_4)_2SO_4$] is the main source of N that, together with organic fertilizer and industrial and other air pollution, ensured adequate S supply. Oil palm requires similar amounts of S and Mg, with the literature putting critical levels of both nutrients in frond #17 at 0.2% (Fairhurst et al., 2005). Out of the several amino acids that make up plant protein, cysteine and methionine contain S, and the ratio of N to S in plant protein often is about 15. Sulfur is an important component of oil synthesis and many oil crops respond strongly to S supply although there are no reports of S responses in oil palm.

In contrast to Malaysia, urea is the main source of N for oil palm in Indonesia, while other fertilizers containing S such as single superphosphate ($Ca(H_2PO_4)_2 + 2CaSO_4$) are seldom used. As a consequence, the S status has declined in Indonesia due to its removal with the harvested fruit and S losses to leaching. Sumbak (1983) and then Ng et al., (1988) predicted that the trend towards high-analysis fertilizers and high-yielding palm varieties would lead to widespread S deficiency in Indonesia.

**Abbreviations and notes: N = nitrogen; Mg = magnesium; S = sulfur.**

IPNI SEAP Photo

**Measuring and preparing** oil palm reference frond #17 sample for plant analysis.

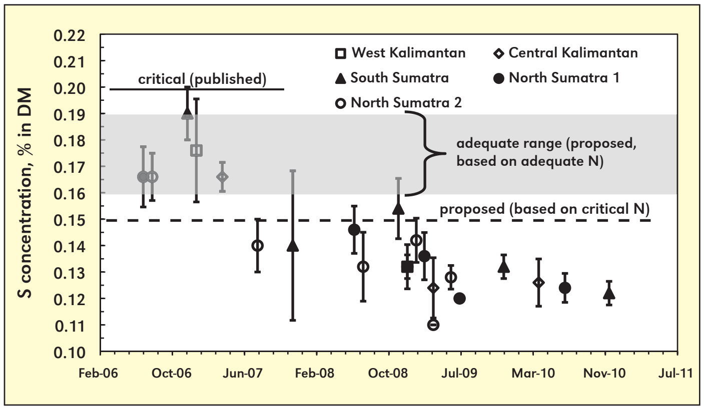


**Figure 1.** Change in sulfur concentration in frond #17 at selected sites sampled between 2006 and 2011 (means ± standard deviation).

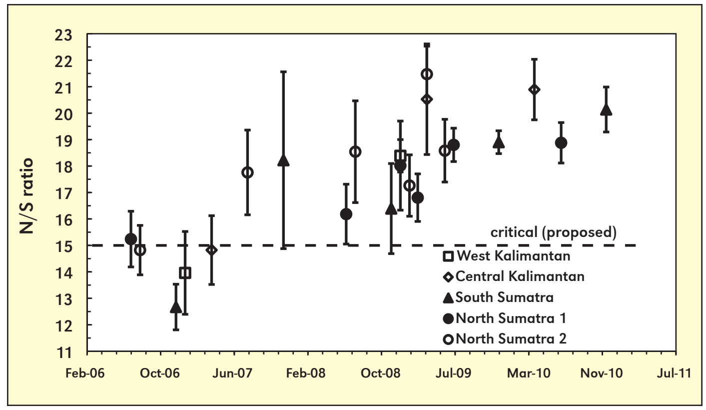


**Figure 2.** Change in nitrogen to sulfur ratio in frond #17 at selected sites between 2006 and 2011 (means ± standard deviation).

At this time there were a few reports of low leaf S concentration. Wigena et al., (2006) found 0.14% S in leaves in an S-free fertilizer treatment, who was preceded by Turner et al., (1983) indicating S deficiency in nursery seedlings in North Sumatra.

Best Management Practice (BMP) projects conducted by the IPNI Southeast Asia Program (SEAP) on sustainable intensification of oil palm (Donough et al., 2009) have analyzed nutrient status, including S, of oil palm in Indonesia. From July 2006, IPNI SEAP has established BMP projects on 30 commercial blocks with a total area 1,082 ha in partnership with collaborating plantations at two sites in North Sumatra and one each in South Sumatra, and West, Central, and East Kalimantan. These sites span the range of conditions where oil palm is currently grown in Indonesia. Corresponding blocks with standard estate practices (SEP, total area 1,104 ha) were compared to the BMP blocks. Each block was sampled for plant nutrient status between 2006 and 2011. Leaf tissue from reference frond #17 was sampled from every tenth palm in every tenth row and analyzed for nutrient content. Results for N and S from the SEP blocks were used in this study.

## Leaf Sulfur Status

From the start of sampling, S status was far below 0.20% S, the published critical concentration (Calvez et al., 1976; Fairhurst et al., 2005). Moreover, there was a continuous decline over time in leaf S status at all sites. The S concentration in leaves of adult oil palm in Colombia was below the 0.2% margin in most of the plantations surveyed (Dávila et al., 2000). These data challenge whether 0.20% S is a satisfactory critical value.

The N:S ratio is used for crop diagnosis with some limitations mainly because N is more mobile than S. Critical N:S ratios for wheat, rapeseed-mustard, maize, and alfalfa in the Indo-Ganges plain were 16, 15.5, 11, and 16, respectively (Khurana et al., 2008). This agrees with the typical N:S ratio of 15 for plant proteins. Mean N:S ratios in frond #17 of oil palm were measured at 15.1 (Breure and Rosenquist, 1977), which suggests that a critical N:S ratio of 15 would be reasonable for oil palm.

The critical N concentration in frond #17 of mature oil palm is 2.3% (Von Uexküll and Fairhurst, 1991). Applying the N:S ratio of 15 gives a critical S concentration of 0.15%. Khalid and Zakaria (1993) applied variable levels of S to oil palm, including an S-free control, for seven years. They saw no symptoms of S deficiency and measured leaf S concentrations between 0.16 and 0.30%—the lower concentration confirming the 0.15% proposed here.

The data from the BMP project show that the S status was marginal at the start and declined over time, approaching a baseline value of around 0.12% (**Figure 1**). Correspondingly, N:S ratios increased steadily during the course of the experiment reaching mean values of above 20 at several sites (**Figure 2**). N:S ratios on all sites in 2009 were above 15, ranging between 17.9 to 20.5, although the differences were not significant ($p > 0.05$). Sulfur concentrations were only 80% of the new critical value of 0.15% (**Figure 1**).

A yield response to S fertilizer can be expected, but this needs experimental validation. IPNI is therefore planning to establish field trials to (1) re-evaluate the critical S concentration in leaf tissue of oil palm and (2) assess the yield response to S supply.

The cost of applying fertilizer S is small compared with potential gains in oil yield. The expected impact of S on N use efficiency, oil synthesis and kernel quality will convince plantation managers to apply S fertilizer. Sulfur source options will depend on fertilizer cost and availability. In Indonesia, several mineral fertilizers containing S are available [e.g., $(NH_4)_2SO_4$, potassium sulfate ($K_2SO_4$), magnesium sulfate ($MgSO_4$), potassium magnesium sulfate ($K_2SO_4 \cdot 2MgSO_4$), single superphosphate], but are either expensive or of limited availability. Kieserite ($MgSO_4 \cdot H_2O$), which is easily available, is also a good immediate option. With 16% Mg and 21% S, it matches oil palm's requirements. As a general precaution against S deficiency it is suggested to include S at 10% of the N dose in the fertilizer regime.

## Summary

Based on a critical N:S ratio of 15 in the leaf tissue of oil palm and a critical N concentration of 2.3%, we suggest that the critical concentration of S be decreased from 0.20% to 0.15%. Leaf samples taken from six sites across Indonesia had S concentrations of 0.12 to 0.13%, which are lower than even this new critical value. It is concluded that (1) oil palm plantations need to include S in their routine leaf analysis, particularly if they do not apply fertilizer containing S; (2) S concentration in frond #17 less than 0.15% requires remedial application of fertilizer containing S; and (3) researchers and agronomists should become aware that S is an essential nutrient for oil palm.

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*This paper is summarized from J. Gerendás et al. in Oil Palm Bulletin 67 (November 2013), pp. 5-10.*

IPNI SEAP Photo

**Planters** should be aware of sulfur deficiency.

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# IPNI Science Award – Nominations Are Due September 30, 2015

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.

Description and Nomination Format for the

IPNI Science Award

A Program of the International Plant Nutrition Institute (IPNI)

IPNI

Nomination deadline: September 30, 2015
Award announcement date: December 15, 2015

**Past Winners**

2014: Dr. A.D. Halvorson, of the United States Department of Agriculture - Agricultural Research Service (USDA-ARS).
2013: Minimum requirements for the award were not met.
2012: Mr. A.E. Johnston of Rothamsted Research.
2011: Dr. M.J. McLaughlin of the Commonwealth Scientific and Industrial Research Organisation (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. J. Ryan of the International Center for Agricultural Research in Dry Areas (ICARDA).
2007: Dr. M. 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, 2015. Announcement of Award recipient will be on December 15, 2015.

**An individual Award nomination package will be retained and considered for two additional years (for a total of three years).** There is no need to resubmit a nomination during that three-year period unless a significant change has occurred.

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

# Ginger Yield and Quality Influenced by Potassium Fertilization

By Lujiu Li, Fang Chen, Jiajia Wang, Dianli Yao, and Pingping Wu

**Farmers are underemphasizing the application of K fertilizer** in the face of increased nutrient demand by the crop. **Maximum benefits from K** were observed with the application of 450 kg $K_2O$/ha, when balanced with adequate N and P.

Ginger (*Zingiber officinale*) is an important industrial crop of China. Its rhizomes contain balmy essential oil and pungent Gingierone, making it popular as a flavoring agent, in Chinese medicines, and as a special vegetable in people's daily diets worldwide. China is currently one of the largest ginger producing countries in the world. Recent statistics indicate that the ginger production area in China has reached 240,000 ha, which accounts for 48% of the world's ginger-growing area (Ministry of Agriculture, 2006). Anhui is one of the leading ginger-producing provinces in China, where ginger planting has become a primary income source for local farmers.

Ginger requires large quantity of nutrients, especially K, for successful cultivation. However, in both Anhui and other areas in China, farmers usually over apply N and P fertilizers, while K fertilization is ignored. This imbalance in N, P and K applications results in low rhizome yield and inferior quality of ginger. Field experiments were conducted on a loam soil from 2007 to 2009 in Shanqiao and Yangqiao towns, Linquan county of Anhui to evaluate the effects of K application on ginger rhizome production. Some physical and chemical properties of the top 20 cm of all experimental soils are listed in **Table 1**. Available K was deficient in all the soils.

Potassium fertilizer at five different rates (0, 225, 450, 675, and 900 kg $K_2O$/ha applied as KCl) was broadcast in different plots before ginger transplanting each year of the experiment. All plots received 450 kg N (urea) and 90 kg $P_2O_5$ (DAP) per ha in each year as well. For all the experiments, basal fertilization included all of the P and K fertilizers plus 60% of the total N fertilizer, while the remaining 40% N was equally applied in two topdressings at about 105 and 135 days after ginger transplanting. The cultivar was local 'Lion-head' ginger planted at 106,000 plants/ha.

Ginger plants without K fertilization gradually showed K deficiency symptoms—from pale green to yellow coloration along the tip and edge of the older leaves in the lower part of the plant, while the veins of leaves remained green. Eventually the whole leaf withered, died, and fell with the development of K deficiency, and the whole plant became stunted with small leaves (**Figure 1**). Ginger plant grew normally in the treatment supplied with 450 kg $K_2O$/ha, and did not show any K deficiency symptoms.

Ginger rhizome yield responded significantly to K applications (**Table 2**). In 2007, K application with 225 to 900 kg $K_2O$/ha increased ginger rhizome yields by 13 to 41% (average 26%) as compared to no K treatment. The medium K application rate (450 kg $K_2O$/ha) produced the highest rhizome yield, while the highest K application rate (900 kg $K_2O$/ha) actually resulted in significantly lower rhizome yields than those obtained with K application rates of 225 or 675 kg $K_2O$/ha. The probable reasons for this yield decrease can be either excessive K application leading to imbalanced ginger plant nutrition compared to N and P, or $Cl^-$ toxicity as ginger is a $Cl^-$ sensitive crop. The K response trends were similar across all the three years as the yield of ginger rhizome increased by 18 to 45% (average 39%) in year 2, and by 14 to 37% (average 34%) in year 3 when compared with no K treatment.

**Table 2.** Fresh rhizome yields of ginger as affected by potassium application rates, Anhui, China.

| kg $K_2O$/ha | 2007 | 2008 | 2009 | Average |
|---|---|---|---|---|
| | Yield, t/ha | | | |
| 0 | 32.3 d | 34.9 d | 42.8 c | 36.7 d |
| 225 | 40.9 b | 45.4 b | 55.1 a | 47.1 b |
| 450 | 45.6 a | 50.7 a | 58.5 a | 51.6 a |
| 675 | 39.5 b | 43.6 bc | 52.2 ab | 45.1 bc |
| 900 | 36.5 c | 41.4 c | 48.9 b | 42.2 c |

Values in each column followed by different letters are statistically different at $p = 0.05$.

Various indicators of ginger rhizome quality as affected by K fertilization are shown in **Table 3**. Among all quality parameters, vitamin C, soluble sugar, crude protein, nitrate, and nitrite contents of ginger rhizome are the most important to consider. The first three parameters are known to influence edible quality, while the last two parameters govern food security because high concentrations of nitrate and nitrite in ginger rhizome are harmful to human health.

The vitamin C content in ginger rhizomes responded significantly to K

**Table 1.** Some physical and chemical properties of the top 20 cm of experimental soils in Anhui.

| Year/Location | pH | O.M % | Ca | Mg | N | P | K | S | B | Cu | Fe | Mn | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | mg/L | | | | | | | | | | |
| 2007/Shanqiao | 6.2 | 0.8 | 3,306 | 555 | 13 | 15 | 62 | 8 | 0.1 | 1.6 | 42 | 15 | 2.4 |
| 2008/Yangqiao | 6.6 | 1.4 | 3,683 | 473 | 18 | 17 | 59 | 12 | 2.2 | 2.6 | 16 | 69 | 1.2 |
| 2009/Yangqiao | 6.6 | 0.6 | 3,040 | 507 | 14 | 37 | 70 | 13 | 0.6 | 3.1 | 61 | 50 | 1.7 |
| Critical values* | – | – | 401 | 122 | 50 | 12 | 78 | 12 | 0.2 | 1.0 | 10 | 5.0 | 2.0 |

*Critical values were determined using the procedure of Portch and Hunter (2002) and are used by the National Laboratory of Soil Testing and Fertilizer Recommendations in Beijing.
O.M. = organic matter; Ca = calcium; Mg = magnesium; S = sulfur; B = boron; Cu = copper; Fe = iron; Mn = manganese; Zn = zinc.

**Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; $Cl^-$ = chloride; DAP = diammonium phosphate; KCl = potassium chloride. IPNI Project CHN-AN10**

**Table 3.** Effect of potassium application rates on quality of ginger rhizome (average of 3 years), Anhui, China.

| kg $K_2O$/ha | Vitamin C, mg/kg | Soluble sugar, % | Crude protein, % | Nitrate, mg/kg | Nitrite, mg/kg |
|---|---|---|---|---|---|
| 0 | 33.8 c | 3.35 b | 11.9 b | 160.7 a | 3.85 a |
| 225 | 38.2 b | 3.62 ab | 13.3 a | 115.5 b | 3.44 b |
| 450 | 44.2 a | 3.93 a | 13.6 a | 102.3 c | 2.87 c |
| 675 | 39.2 b | 3.63 ab | 13.3 a | 107.4 bc | 2.96 c |
| 900 | 32.3 c | 3.39 b | 11.7 b | 118.8 b | 3.65 ab |

Values in each column followed by different letters are statistically different at $p = 0.05$.

applications (**Table 3**). With K application rates of 225 to 675 kg $K_2O$/ha, there was a significant increase (13 to 31%, average 20%) in vitamin C content of ginger rhizome as compared to the no K treatment. The highest content of vitamin C was obtained with the application of 450 kg $K_2O$/ha, while as with the yield response, the application of 900 kg $K_2O$/ha lowered the content of vitamin C in rhizomes by 4% when compared with the no K treatment.

The soluble sugar content of ginger rhizomes responded to K applications quite differently than vitamin C content (**Table 3**). In general, the soluble sugar content increased by 1 to 17% (average 8%) across K treatments ranging from 225 to 900 kg $K_2O$/ha over no K treatment. However, most of these increases were not statistically significant. The highest soluble sugar content was found with the application of 450 kg $K_2O$/ha, but the value wasn't statistically different from the soluble sugar contents found with applications of 225 and 675 kg $K_2O$/ha. The effect of K applications on crude protein content in ginger rhizomes was similar to that on soluble sugar content. With $K_2O$ applications of 225, 450 and 675 kg/ha, the crude protein content increased significantly by 12, 15 and 12% on average, respectively, as compared to no K treatment. The highest crude protein content was obtained with $K_2O$ application of 450 kg/ha, while higher K applications were not beneficial in improving the crude protein content of rhizomes.

Nitrate and nitrite contents of ginger rhizomes responded significantly to different K application rates (**Table 3**). Applications of 225 to 900 kg $K_2O$/ha significantly reduced the contents of nitrate by an average of 31% (range of 26 to 36%) and nitrite by an average of 16% (range of 5 to 25%) in ginger rhizomes. Both nitrate and nitrite contents first dropped and then increased as K application rates increased, with the lowest values obtained with the application of 450 kg $K_2O$/ha.

Results from a series of demonstration trials conducted for three years in ginger-growing areas of China showed significant rhizome yield increases and economic benefits when fertilizer K application was balanced with other nutrients. Rhizome yield increased from 44 to 56 t/ha (26%) and farmer profits increased by US$3,213 (range of US$2,248 to 4,002 across the three years) by increasing farmer's K application rates by an average of 26%.

## Summary

Potassium application at 450 kg $K_2O$/ha significantly increased yield and improved quality parameters of ginger rhizomes grown on K deficient soils in Anhui. More attention needs to be paid to potential K requirements of the ginger crop in Anhui and other ginger-growing provinces, where K deficiency may become more serious in future due to extensive K mining of soils and the adoption of high-yielding ginger cultivars and/or more intensive cropping systems. BC

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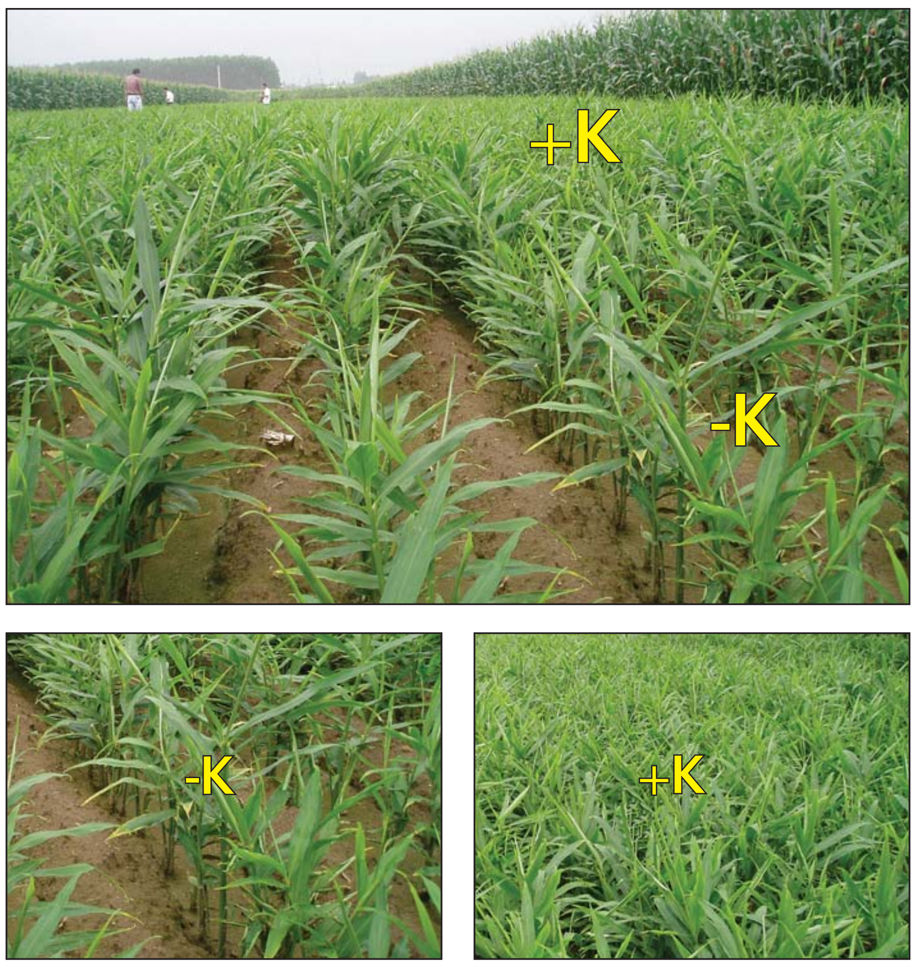


**Figure 1.** Ginger crop response to fertilizer 450 kg $K_2O$ per ha. Plants grown without K shown in the foreground in top photo and in the bottom left photo. Plants grown with K shown in the background in top photo and in the bottom right photo.

# Coffee–Forage Intercropping is a Sustainable Production System for Brazil

By José Laércio Favarin, Tiago Tezotto, Adriene Woods Pedrosa, and Ana Paula Neto

**Cover crop forage grown under the coffee plant canopy** serves as an important biomass source, which is proving effective at protecting this agro-ecosystem while improving the use of N.

Brazil is the world's largest producer of both arabica (*Coffea arabica* L.) and robusta (*Coffea canephora* Pierre ex A. Froehner) coffee species. The two species are cultivated on an estimated 2.3 million ha in Brazil with an average of 2.1 to 3 million tons of coffee processed each year.

Coffee grows in the extensive tropical region of Brazil characterized by two main seasons, the rainy season (from September to April) and a dry season (from May to September). In Brazil, the crop is largely grown under full-sun growing conditions, which is different from other large coffee-growing areas like Central America where the crop is commonly planted within a shaded agroforestry system.

Water is commonly limited in perennial plants grown under full-sun, tropical conditions, and it is important to minimize water loss from surface runoff and evaporation. Evapotranspiration varies from 3 to 5 mm per day (i.e., 3 to 5 L water/m$^2$/day). Soils are highly weathered with kaolinite and oxides present in the clay fraction. The dominant presence of these clay minerals limits soil water retention capacity to less than 0.5 mm per cm of soil (i.e., 0.5 L/m$^2$/cm).

Forages like *Urochloa decumbens*, *Urochloa ruziziensis*, and more recently, *Urochloa brizantha* are being intercropped on Brazilian plantations to accomplish the goals of protecting soil from the impact of torrential rainfall that is common in the tropics and reducing soil heating due to exposure to the sun.

A coffee–forage intercropping system contributes to the goal of improving water availability, especially during the first six to eight years of establishment, when the plants are only exploiting a fraction of the total area. For example, the presence of 3 t/ha of biomass increased soil moisture by 49% when compared with amounts measured without biomass addition (unpublished data).

Forage biomass can increase water infiltration and reduce the speed of surface runoff, which both contribute to less soil loss by water erosion. Further, the temperature of soil surfaces (5 cm depth) often do not exceed 35°C. This is far less than 50°C temperatures that are commonly observed on exposed soil surfaces, leading to root system stress and even root death.

In addition to protecting the soil, forage biomass can also increase fertilizer N recovery in its role as a cover crop. Nutrients absorbed from the soil volume through forage root growth in inter rows are recycled within the cropping system. Around 3 t/ha of forage biomass could provide the equivalent of 24 to 92 kg N/ha with a low release by decomposition of biomass under the coffee canopy (Pedrosa, 2013).

Despite the numerous advantages of forage cultivation in a coffee-forage system, producers can often justify resisting its adoption due to misperception of yield-robbing nutrient, mainly N, competition. In crop systems in which there is input of fresh biomass, there is commonly an increase in availability of oxidizable C as a energy source for microorganisms and this decomposition immobilizes soil N (or releases N) depending on the C:N ratio of the added biomass.

**Abbreviations and notes: N = nitrogen; C = carbon.**

Ana Paula Neto

**Coffee-forage** (*Urochloa* sp.) intercropping system.

Addition of biomass with a C:N ratio above an equilibrium of 33:1 results in N immobilization due to the incorporation of the C source into the soil microbial biomass. Biomass C:N ratios below this equilibrium will increase soil N, since the supply exceeds microbial demand (**Figure 1**).

Coffee plantations harvest forage biomass with a shredder, which distributes the biomass over the desired area. Biomass residue input commonly ranges between 3 and 5 t of dry matter/ha/yr. During every forage harvest/spreading operation, biomass nutrients taken from a region where coffee plants

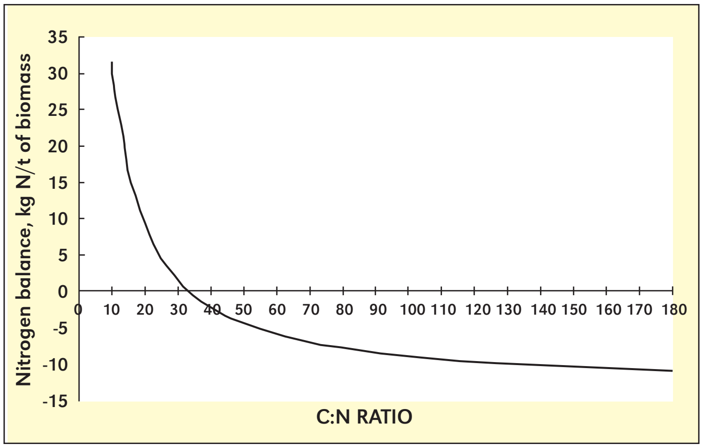


**Figure 1.** Impact of forage biomass on soil N balance with increasing C:N ratio (from Cantarella, 2007).

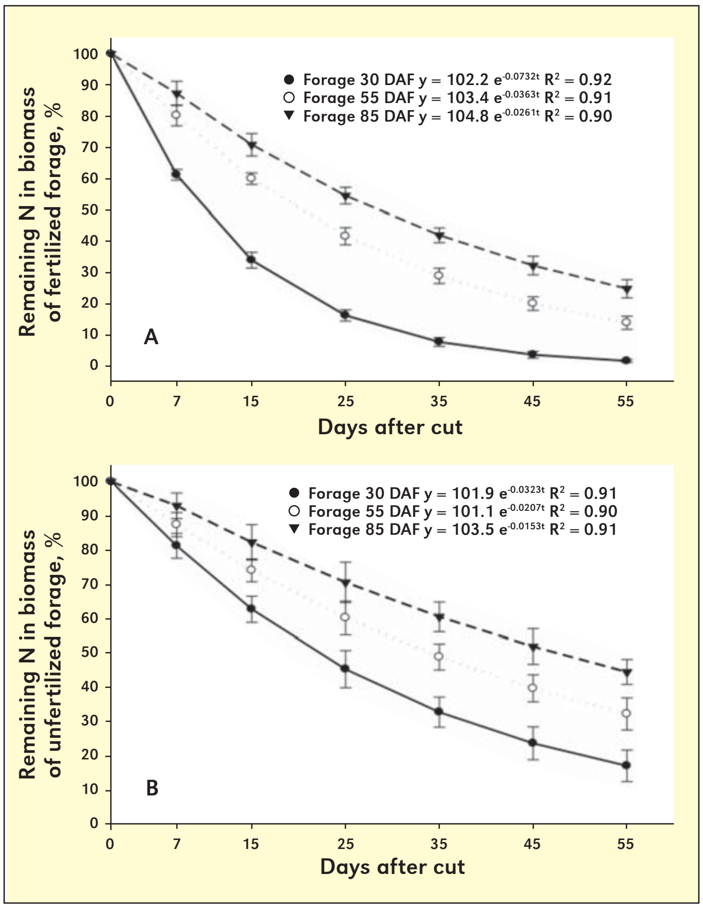


**Figure 2.** Nitrogen release from forage biomass fertilized (A) and unfertilized (B) with N, cut at 30, 55 and 85 days after fertilization (DAF) (from Pedrosa et al., 2014).

explores a low volume of soil due to crop formation stage, are transferred to the coffee canopy zone that is highly explored by coffee roots. After each forage harvest, a proportion of the forage root system dies, leaving channels or stable biopores that contribute to rain infiltration and oxygen exchange within the soil profile. A forage harvest/spreading operation done at 30 and 45 day intervals has been demonstrated to not immobilize significant N supplies to coffee since the biomass C:N ratio is maintained below 35:1 (Pedrosa et al., 2014).

When evaluating biomass it is important to know the half-

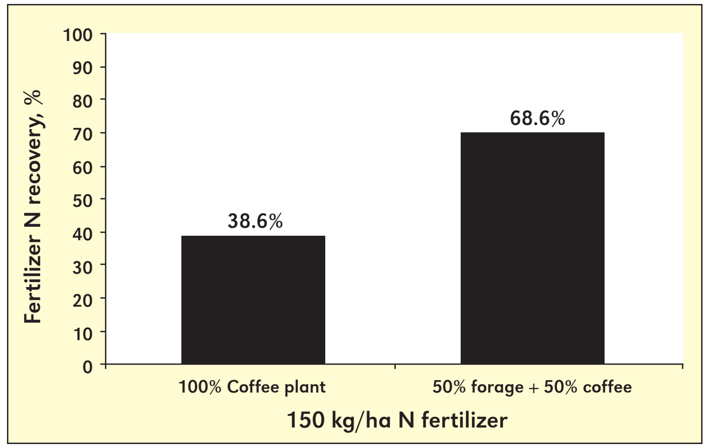


**Figure 3.** Recovery (%) of $^{15}N$ in coffee applied via fertilizer. Application of 150 kg N/ha in coffee plant (100% of the dose) and application of 75 kg/ha in coffee plant (50% dose) and 75 kg/ha in forage grass (50%), which is cut and deposited in coffee plant canopy (unpublished data).

life time for its residue decomposition—the time required to decompose 50% of the biomass applied. This also applies to rate of N released from the biomass. An example of the release of 50% of N present in biomass due to both forage fertilization and cutting time is shown in **Figure 2**. Forage N fertilization increased the rate of its biomass decomposition with 50% of the N released within 10 days (cut 30 days after N fertilization), 20 days (cut 55 days after N fertilization) and 30 days (cut 85 days after fertilization). In comparison, forage not receiving N (the most common situation) released 50% of N present over 20, 35 and 55 days under the same three cutting intervals.

Many coffee-forage intercropping system advantages have been observed in coffee field areas in Brazil. Field research to assess N balance due to biomass C:N ratio and fertilizer N recovery, through $^{15}N$ isotopic technique for this system, is now underway. Preliminary results indicate that there is an increase in the order of 30% in the efficiency of N fertilization in this system (**Figure 3**).

## Summary

Forages can recover around 85% of fertilizer N applied and then release this N during residue decomposition under the coffee canopy, which is then readily absorbed by the coffee crop. Early results highlight the sustainability of this coffee-forage intercropping system due to its conservation of water, soil and N. BC

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# Precision Nutrient Management in No-till Wheat: A Case Study for Haryana

By Tek B. Sapkota, Kaushik Majumdar and M.L. Jat

**Poor understanding of nutrient management in no-tillage-based wheat** spurred a comparison of various available strategies.

**The greatest overall benefit was generated** with Nutrient Expert®-based fertilizer recommendations supplemented with GreenSeeker®-guided N application.

Wheat is the second most important cereal crop in India occupying about 29 million ha, which contributes to 37% of the country's foodgrain production. Nearly 50% of the total wheat production in India comes from the Northwestern (NW) plain zone. Surveys done in this region have revealed that farmers often apply greater than recommended rates of fertilizer N and P, but ignore the application of K and other secondary and micronutrients. This leads to reductions in crop yield, nutrient use efficiency, farmer profit, and also increases environmental risks associated with the loss of unutilized nutrients through gaseous emissions or leaching. The Intergovernmental Panel on Climate Change (IPCC) loosely assumes that 1% of fertilizer N applied in the field is emitted as $N_2O$, but this fraction can be much higher in areas with imbalanced fertilization like in NW India.

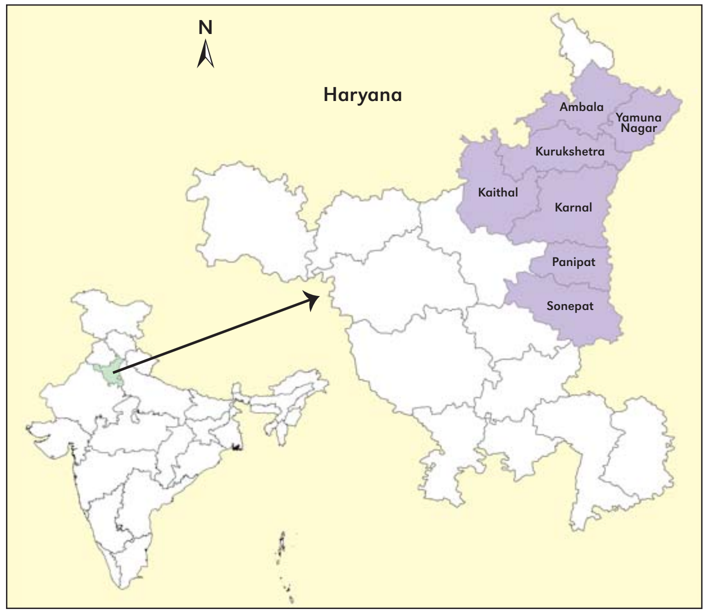
Recent advances in the development of precision nutrient prescription tools like Nutrient Expert® (NE), a decision support system (Pampolino et al., 2012), GreenSeeker® (GS) handheld sensors, and leaf color charts (LCCs) have shown promise in increasing crop productivity and nutrient use efficiency of crops and minimizing environmental footprints (Satyanarayana et al., 2012).

In a collaborative effort between the International Maize and Wheat Improvement Center (CIMMYT) and the International Plant Nutrition Institute (IPNI) to test, pilot and upscale NE-based fertilizer management, on-farm participatory research was conducted in seven districts (Karnal, Kurukshetra, Kaithal, Ambala, Sonepat, Panipat, and Yamunanager) of Haryana to evaluate and compare NE-based strategies in conventional and no-till wheat production systems. For this, 15 on-farm experiments were established in 2010-11 and 2011-12. The four nutrient management treatments included: (1) NE-based recommendation; (2) NE+GS: NE recommendation supplemented with GS-guided application of N; (3) SR: state fertilizer recommendation; and (4) FFP or the farmers fertilization practice. These treatments were compared for agronomic productivity, economic profitability and total greenhouse gas emissions. Total greenhouse gas emissions from wheat production were estimated using the Cool Farm Tool (Hillier et al., 2011). This tool uses information about soil and climatic characteristics, tillage and residue management, crop management practices such as fertilizer and pesticide applications, energy use and total output.

## Grain Yield and Economic Profitability

Averaging data for two years, results showed that the highest grain yields were obtained using NE-based nutrient management (NE and NE+GS) strategies followed by SR and FFP (**Figure 1**). Grain yields were not significantly different between NE and NE+GS. Similarly, net returns were also significantly different among various nutrient management strategies. However, net return was not different significantly among NE, NE+GS and SR (**Figure 1**). The total cost of production was not significantly different among the different nutrient management strategies tested (data not shown). Therefore, lower grain and straw yield were mainly responsible for lower net returns under FFP as compared to other nutrient management strategies.

**Abbreviations and notes: GWP = global warming potential; N = nitrogen; P = phosphorus; K = potassium; $N_2O$ = nitrous oxide; US$1 = ₹64.**




**Study districts** in the Haryana state.

Imbalanced fertilizer application due to non-application of fertilizer K (Sapkota et al., 2014) was probably the main reason for lower grain yield under FFP compared to other treatments. Nutrient recommendations in NE-based strategies were derived after accounting for the native nutrient supplying capacity of soil, nutrient balance in the concerned field at the cropping system level and yield target and therefore, were possibly more balanced compared to the other treatments.

## Global Warming Potential

Estimated GWP, as affected by nutrient management strategy, was significant for both GWP per t wheat yield and GWP per US$ net return. For example, FFP resulted in higher GWP per t of wheat yield whereas NE-based recommendation followed by GS-based N application resulted in the lowest GWP

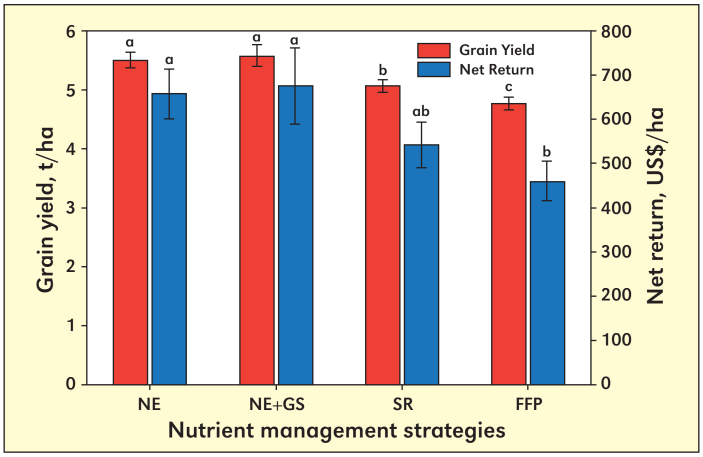



**Figure 1.** Wheat grain yield and net returns under no-tillage system as affected by different nutrient management strategies in Haryana. The data is the mean of two years from 15 farmers' fields (i.e., n=30). Means followed by different letters within same variable are significantly different based on LSD 0.05. Vertical bars show standard errors of the means. NE: Nutrient Expert®, NE+GS: Nutrient Expert® supplemented with GreenSeeker®, SR: State recommendation, and FFP: farmers' fertilizer practice.

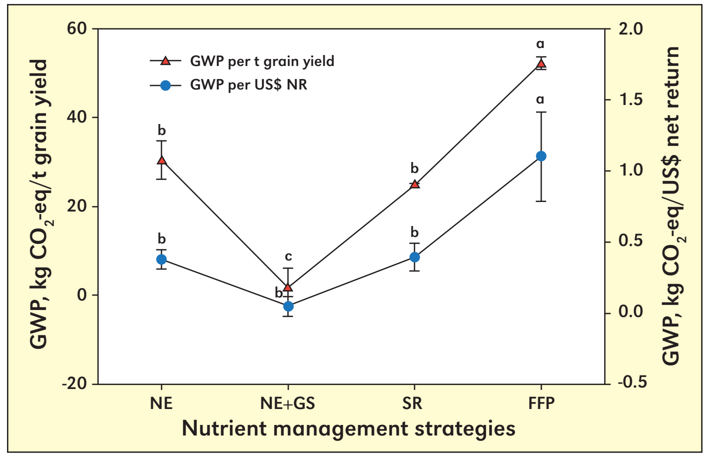



**Figure 2.** Total Global Warming Potential (GWP) per t grain yield and per US$ net return (NR) under different nutrient management strategies in no-till wheat production systems in Haryana. The data is the mean of two years from 15 farmers' fields (i.e., n=30). Means followed by different letters within same variable are significantly different based on LSD 0.05. Vertical bars show standard errors of the means. NE: Nutrient Expert®, NE+GS: Nutrient Expert® supplemented with GreenSeeker®, SR: State recommendation, and FFP: farmers' fertilizer practice.

**Table 1.** Cost of key inputs and outputs used for economic analysis during two wheat growing seasons.

| Particulars | 2010-11 | 2011-12 |
|---|---|---|
| Minimum support price of wheat grain, ₹/kg | 11.20 | 12.85 |
| Market price of wheat straw, ₹/kg | 2.50 | 2.50 |
| Labor wage, ₹/person/day | 150 to 200 | 200 to 250 |
| Urea, ₹/kg | 4.70 | 5.36 |
| Diammonium phosphate, ₹/kg | 10.00 | 18.20 |
| Potassium chloride, ₹/kg | 9.00 to 10.00 | 11.00 to 12.00 |
| Zinc sulfate, ₹/kg | 20.00 | 25.00 |
| Seed, ₹/kg | 16.25 | 18.00 |
| Seed treatment, ₹/kg | 1.25 | 1.25 |
| Diesel cost, ₹/L | 36.49 | 39.92 |
| Electricity charge, ₹/kWh | 0.30 | 0.30 |
| Hiring cost of harrow/tiller, ₹/ha/pass | 550 to 625 | 750 to 800 |
| Planking cost, ₹/ha/pass | 250 to 375 | 350 o 500 |
| Land rent, ₹/ha/season | 35,000 | 37,500 |
| Interest on working capital, percent/year | 12.00 | 12.00 |
| US$1 = ₹64. | | |

per t of wheat (**Figure 2**). A similar trend was observed for GWP per US$ of net return.

Broadcast application of relatively larger amounts of N fertilizer under FFP was mainly responsible for higher total GWP as compared to other nutrient management strategies. Further, lack of K fertilizer in FFP probably reduced recovery of other nutrients by wheat, thereby reducing yield. This ultimately resulted in higher GWP per unit of produce under FFP. Our estimates show that no-till wheat production under a NE-based recommendation supplemented with GS-guided N management can be carbon neutral both in terms of yield and net return. This effect can be attributed to better nutrient use efficiency from in-season precision N application (i.e., rate and number of split applications matching the physiological demand of wheat). This probably reduced residual nitrate-N in soil profile, thereby minimizing the N loss in the form of $N_2O$ emissions.

## Summary

Both grain yield and net return were higher with NE-based strategies compared to FFP and SR. The estimated total carbon footprint (i.e., GWP per t of wheat grain production and per US$ of net return) was also lower for NE-based strategies than other nutrient management strategies. Thus, the use of precision nutrient management tools such as Nutrient Expert® and GreenSeeker® are important for increasing wheat yields and farmer profits yet minimizing the environmental footprint of wheat production.

## Acknowledgements

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*This article was adapted from the author's work published in Field Crops Research (155:233-244).*

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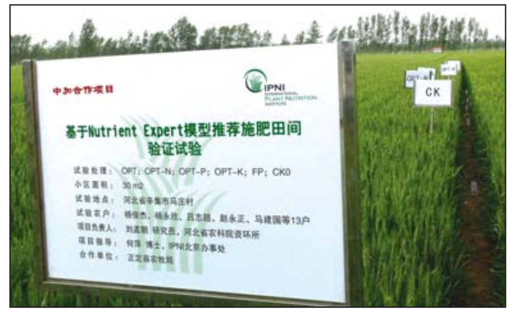
# Nutrient Expert® – Going Global with Improved Fertilizer Recommendations

By Adrian M. Johnston




**Eight years of software development** has grown both the confidence and understanding of how Nutrient Expert® can help meet the needs of small farmers.

Addressing the challenge of making science-based fertilizer recommendations to smallholder farmers throughout Asia and Africa has been a key focus of IPNI staff over the decades. As students of agriculture we all learned about soil testing methods, correlation and interpretation as the key step in this process. However, this entire approach has not been successful on smallholder farms due to access, cost or inadequate timeliness in delivery of results. As a result, some alternative had to be found to address this problem for smallholder farmers in Asia and Africa.

The development of the decision support software, Nutrient Expert®, by IPNI staff came about to address the grow-

ing need for science-based fertilizer recommendations for smallholder farmers in Asia and Africa. After almost 8 years of development, verification and application of the software, we have grown in both confidence and understanding of how successful this tool will be in helping meet the needs of small farmers. With software now available for downloading from the web (http://software.ipni.net) IPNI is providing a free of charge option for making nutrient recommendations for wheat and maize production in Asia. A rice tool is currently under pre-release large-scale validation phase in Asia. A maize tool for sub-Saharan Africa is close to release, and a wheat tool for North Africa is in development, as are soybean tools for Asia and a cotton tool in South Asia. Work has just recently started to develop a tool for cassava in SE Asia and central Africa.

In the course of research and extension program development in IPNI, one of the key questions always being asked is can this technology or practice be taken to scale? Where might it be applicable within other agricultural systems and regions of the world? With the success of the Nutrient Expert® program, getting other staff and programs of IPNI interested in adapting the tool to their regions was relatively easy—success was our best selling tool. However, how would such a tool be moved to a more open, public scale allowing the access and use by others?

Having the Nutrient Expert® tools available for downloading from the web is one way of providing open access to all interested stakeholders. Currently we are developing versions that use databases on the web, allowing the tool to be run as a web-based version and enabling easy updating of the available tools. We are also investigating the options for moving the Nutrient Expert® tool to a mobile platform, where agriculture extension and industry workers would be able to access and use the software with a tablet in the farmers field. All of these improvements are being developed in cooperation with the IT industry, where the expertise to succeed in delivery of the technology exists. Finally, IPNI also has to decide when, and if, they are going to release the programming code for Nutrient Expert® to the public. As with all crop production support models, it is likely an improved version is out there once our current technology gets into the hands of others with additional ideas to pursue the continuous improvement we would like to see. BC



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# Switchgrass Responds Well to Nitrogen in the Arkansas Delta Region, but Not to Phosphorus or Potassium

By V. Steven Green, Charles P. West and Alexandre Rocateli

**A one-cut harvest system for switchgrass grown for biomass bioenergy** places lower P and K demand compared to similar grasses used for forage.

**High N responses can be expected,** but the specific application rates are highly dependent on fertilizer cost and potential revenue from the sale of biomass.

Photos courtesy S. Green

**Switchgrass fertility field trials** located in Colt, Arkansas.

The southern United States has a humid climate. Agricultural soils in the region have provided food, feed, and fiber for many generations. More recently, fuel production has been added to the products that we demand from our agricultural enterprise. Many traditional summer annual crops, such as maize and soybean, have been used in bioenergy production. Biomass crops, such as switchgrass (*Panicum virgatum*), have received much attention for their potential use for cellulosic ethanol production. Biomass crops are not new to the agricultural enterprise nor to this region. However, biomass crops have traditionally been grown for animal feed.

Current fertilizer recommendations for switchgrass are based on native warm-season grasses used as forages, normally harvested as hay in early to mid-summer or grazed by livestock. Under these conditions and timing, N-P-K removal rates are typically much greater than when harvested in the fall after the crop senesces and dries down. Fall harvest of a perennial grass crop, as for biomass bioenergy, returns some of the macrontrients to the soil or to the roots and crowns for recycling back into subsequent year regrowth. This phenomenon could result in N, P and K recommendations that are lower than when the same grasses are utilized as forages.

A field study was conducted from 2011 to 2014 at the University of Arkansas Pine Tree Experiment Station located near Colt, AR. The study site consisted of Henry and Calloway silt loam soils (Fragiaqualfs and Fraglossudalfs) both with slopes less than 3%. Mean annual precipitation for the experimental study years was 1,120 mm. Switchgrass cultivar Alamo was established in 2009 by planting 11.2 kg/ha pure live seed with a grassland drill. Switchgrass was planted at 1 to 2 cm depth. No N was applied in 2009, but 56 kg $P_2O_5$/ha and 112 kg $K_2O$/ha were applied to the study site. In 2010, 73 kg N/ha was applied.

In 2011, three separate experiments were established at this site to evaluate the effect of N, P and K fertilizer rates on biomass yield. Each of the three experiments was arranged in a randomized complete block design with six replicates. Plots were 2.3 by 8.0 m in size. Four levels of N and five levels of P and K were applied to these experiments as indicated in **Table 1**. Prior to establishing the fertilizer treatments, soil test results indicated that the Mehlich III extractable P was very low to low (8 to 20 ppm) and extractable K was low to medium (50 to 100 ppm) for this soil. In each experiment, the other two primary macronutrients were applied in sufficient quantities such that they would not be limiting (i.e., N applied to P and K trials at 70 kg/ha; P applied to N and K trials at 60 kg $P_2O_5$/ha; K applied to N and P trials at 120 kg $K_2O$/ha).

Fertilizer was spread in late April or early May in each year. No other agronomic manage-

**Table 1.** Fertilizer N, P and K treatments applied from 2011 to 2014.

| N | $P_2O_5$ | $K_2O$ |
|---|---|---|
| ---------- | kg/ha | ---------- |
| 0 | 0 | 0 |
| 50 | 30 | 60 |
| 100 | 60 | 120 |
| 150 | 90 | 180 |
| | 120 | 240 |

Fertilizer was applied in the spring of each year, during the month of May.

**Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; LSD = Least Significant Difference. IPNI Project USA-AR33**

ment was provided during the growing season. Biomass yield samples were taken each fall in late October by harvesting a 1.4 m wide swath through the length of the 8.0 m plot.

## Biomass Yield Response to Fertilizer

Switchgrass biomass yields were not influenced by P or K fertilizer application rates in any of the study years. Mean biomass yields in the P study were 10.8, 13.0, and 13.2 t/ha for 2012, 2013 and 2014, respectively (**Table 2**). Similarly, mean biomass yields in the K study were 10.9, 13.2 and 13.6 t/ha for 2012, 2013 and 2014 (**Table 3**).

Switchgrass biomass yields were significantly affected by

**Table 2.** Switchgrass biomass yields from P fertilizer applications over three years at Colt, AR.

| | 2012 | 2013 | 2014 |
|---|---|---|---|
| kg $P_2O_5$/ha | | t/ha | |
| 0 | 11.2 | 12.3 | 12.2 |
| 30 | 10.6 | 13.1 | 12.8 |
| 60 | 10.4 | 13.3 | 14.6 |
| 90 | 11.4 | 13.1 | 13.2 |
| 120 | 10.3 | 13.0 | 13.0 |
| Mean | 10.8 | 13.0 | 13.2 |
| LSD (0.05) | NS† | NS | NS |

†NS indicates no significant differences at $p = 0.05$.

**Table 3.** Switchgrass biomass yields from K fertilizer applications over three years at Colt, AR.

| | 2012 | 2013 | 2014 |
|---|---|---|---|
| kg $K_2O$/ha | | t/ha | |
| 0 | 10.4 | 12.9 | 13.1 |
| 60 | 11.2 | 13.6 | 13.3 |
| 120 | 10.8 | 12.9 | 13.7 |
| 180 | 10.8 | 13.3 | 13.8 |
| 240 | 11.3 | 13.3 | 14.1 |
| Mean | 10.9 | 13.2 | 13.6 |
| LSD (0.05) | NS† | NS | NS |

†NS indicates no significant differences at $p = 0.05$.

N fertilizer rates in 2013 and 2014, but not in 2012. **Table 4** summarizes yields in the N study from 2012 to 2014. In both 2013 and 2014, N applications increased biomass yield above the 0 N control. In 2014, greater segregation of the treatments was observed with the 100 and 150 kg N/ha treatments providing greater yields than both the 0 and 50 kg N/ha treatments. This is comparable to results by Heggenstaller et al. (2009) who showed increasing yields with N application up to 140 kg N/ha. In their study in Iowa, optimum yields after two years was 13.5 t/ha at 140 kg N/ha N rate. The long growing season in Arkansas shows potential for substantial yields with adequate N application.

The final two years of the three-year study was described as a quadratic response in biomass yield due to N treatment (**Figure 1**). Though maximum yield occurred at the maximum N rate, the incremental biomass increase by increased N rate was only significant above the 50 kg/ha rate in year 2014.

**Table 4.** Switchgrass biomass yields from N fertilizer applications over three years at Colt, AR.

| | 2012 | 2013 | 2014 |
|---|---|---|---|
| kg N/ha | | t/ha | |
| 0 | 10.6 | 9.3 b | 6.7 c |
| 50 | 13.5 | 15.1 a | 12.8 b |
| 100 | 11.9 | 17.5 a | 17.9 a |
| 150 | 15.3 | 19.4 a | 19.6 a |
| LSD (0.05) | NS† | 5.6 | 3.4 |

†NS indicates no significant differences at $p = 0.05$. Different letters within the same column indicate differences among treatments.

Economic returns based on price paid for switchgrass biomass will be the key to whether increased N rates are justified.

The three-year mean response to N rate is shown in **Figure 2**. The fitted linear regression indicates that biomass yield increased by approximately 60 kg for each kg increase in N applied above the control up to the max 150 kg/ha N rate. The yields achieved in this study in Arkansas are somewhat greater than those of Heggenstaller et al. (2009), which was in the 12 to 15 t/ha range. The yields obtained, however, were on the greater end of average yields across a 17 state study where mean biomass yield was 12.9 t/ha for lowland switchgrass

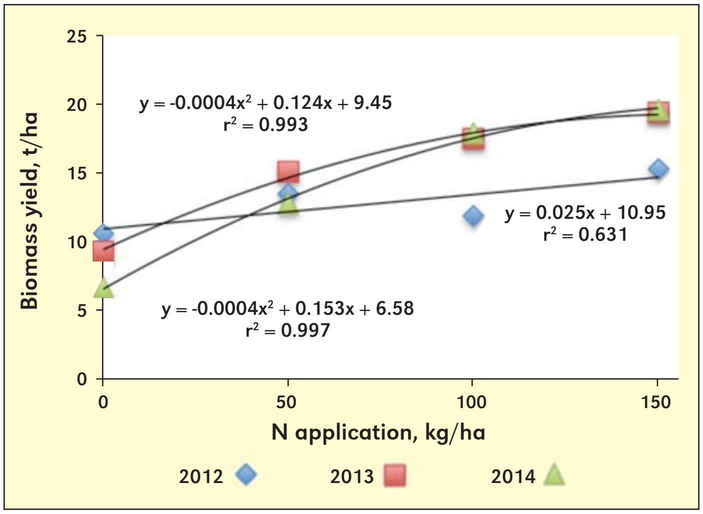


**Figure 1.** Biomass yield response to N rate. Regression fits for 2012 is linear while regression lines for 2013 and 2014 are quadratic.

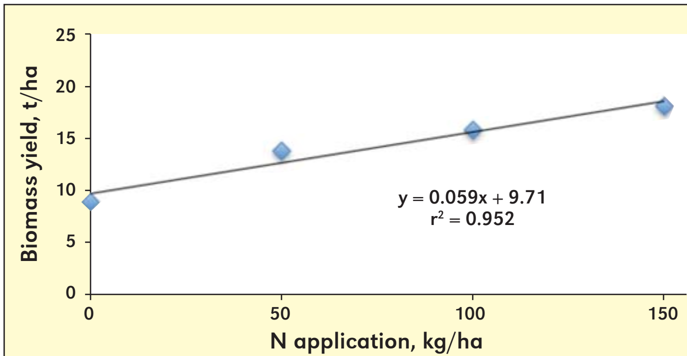


**Figure 2.** Linear regression fit for the means of biomass yields through the three-year study in response to N rate.

varieties such as Alamo (Wullschleger et al., 2010). Our 17 to 20 t/ha yields are in line with N-fertilized switchgrass grown in west Tennessee, which has a similar climate and growing season as our study site in Arkansas (Boyer et al., 2012).

The lack of yield response to P and K fertilizer is not surprising. There is an abundance of evidence that native warm season grasses do not respond to P and K fertilizer, even on low P and K soils (Brejda, 2000; Muir et al., 2001). There is evidence that native warm-season grasses such as switchgrass are able to meet some of their P requirements as a result of symbiotic relationship with arbuscular mycorrhizal fungi (Hetrick et al., 1991). Additionally, native warm-season grasses have low K requirements and are generally able to meet their K requirements without K fertilization, even on low K soils (Taylor and Allinson, 1982).

Even though yield did not respond significantly to P and K fertilizer, the impact on nutrient removal does need to be taken into account. Increasing P fertilizer rates had no impact on N or K removal, but had a slight impact on P removal in 2013 (**Table 5**). Increasing K fertilizer rates had no impact on N and P removal, but had a significant impact on K removal (**Table 6**). Increasing N fertilizer rates had an impact on N, P and K removal (**Table 7**). Since N fertilizer rates impact yield, N will need to be managed in switchgrass production systems. However, this does not mean that P and K fertilizers can be ignored. With N fertilizer rates of 50 to 100 kg N/ha, switchgrass harvest had removal rates of 65 to 86 kg N/ha, 25 to 31 kg $P_2O_5$/ha, and 81 to 99 kg $K_2O$/ha. Management of N fertilizer will necessitate P and K fertilizer applications in order to return P and K removed from switchgrass harvest (Kering et al., 2013). These results are from late season harvest after beginning of senescence of the plant and earlier harvests will likely require even more fertilizer additions than those suggested here.

## Summary

Switchgrass grown for biomass energy in a one-cut system responds to fertilizer N, but not to fertilizer P or K, even on low P and K soils. Nitrogen application rates will need to be determined based on fertilizer cost and potential revenue from sale of biomass with an understanding that higher rates of N have the potential to provide substantial increases in biomass. Over the three-year study, average biomass response to N fertilizer was 60 kg biomass/kg N applied. In addition to N management, P and K fertilizer inputs will need to be managed due to P and K removal with harvested switchgrass biomass in order to sustainably produce switchgrass on an on-going basis. BC

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**Table 5.** Switchgrass N, P and K removal from single fall harvest for biomass at Colt, AR as affected by P fertilizer rate.

| | 2013 | | | 2014 | | |
|---|---|---|---|---|---|---|
| | N | $P_2O_5$ | $K_2O$ | N | $P_2O_5$ | $K_2O$ |
| kg $P_2O_5$/ha | -------- kg/ha -------- | | | -------- kg/ha -------- | | |
| 0 | 50.7 | 23.1 c | 58.7 | 50.8 | 22.0 | 67.3 |
| 30 | 47.9 | 26.1 b | 63.7 | 66.6 | 22.2 | 71.1 |
| 60 | 49.5 | 26.4 ab | 59.3 | 66.2 | 26.6 | 73.8 |
| 90 | 55.7 | 28.2 ab | 60.0 | 54.4 | 26.1 | 72.2 |
| 120 | 42.9 | 28.6 a | 59.6 | 55.8 | 26.1 | 74.2 |
| Mean (all) | 49.3 | 26.6 | 60.2 | 58.8 | 24.5 | 71.7 |
| Mean (fertilized) | 49.0 | 27.3 | 60.7 | 60.8 | 25.2 | 72.9 |
| LSD (0.05) | NS† | 2.3 | NS | NS | NS | NS |

†NS indicates no significant differences at $p = 0.05$.

**Table 6.** Switchgrass N, P and K removal from single fall harvest for biomass at Colt, AR as affected by K fertilizer rate.

| | 2013 | | | 2014 | | |
|---|---|---|---|---|---|---|
| | N | $P_2O_5$ | $K_2O$ | N | $P_2O_5$ | $K_2O$ |
| kg $K_2O$/ha | -------- kg/ha -------- | | | -------- kg/ha -------- | | |
| 0 | 54.0 | 22.5 | 61.3 d | 55.6 | 24.7 | 61.9 c |
| 60 | 54.8 | 23.4 | 79.0 c | 52.4 | 22.7 | 73.0 bc |
| 120 | 51.3 | 23.8 | 84.9 bc | 60.9 | 23.1 | 88.2 ab |
| 180 | 55.7 | 23.8 | 94.4 ab | 51.4 | 24.1 | 103.1 a |
| 240 | 57.0 | 23.6 | 97.1 a | 59.6 | 24.3 | 101.3 a |
| Mean (all) | 54.6 | 23.4 | 83.4 | 56.0 | 23.8 | 85.5 |
| Mean (fertilized) | 54.7 | 23.6 | 88.9 | 56.1 | 23.6 | 91.4 |
| LSD (0.05) | NS† | NS | 11.1 | NS | NS | 15.7 |

†NS indicates no significant differences at $p = 0.05$.

**Table 7.** Switchgrass N, P and K removal from single fall harvest for biomass at Colt, AR as affected by N fertilizer rate.

| | 2013 | | | 2014 | | |
|---|---|---|---|---|---|---|
| | N | $P_2O_5$ | $K_2O$ | N | $P_2O_5$ | $K_2O$ |
| kg N/ha | -------- kg/ha -------- | | | -------- kg/ha -------- | | |
| 0 | 49.9 | 24.3 | 62.5 b | 43.0 c | 15.1 c | 43.2 b |
| 50 | 65.5 | 31.2 | 98.1 a | 67.3 b | 25.0 b | 81.0 a |
| 100 | 75.3 | 31.4 | 99.0 a | 85.9 b | 29.6 a | 91.3 a |
| 150 | 97.9 | 29.8 | 99.5 a | 114.3 a | 31.4 a | 89.1 a |
| Mean (all) | 72.1 | 29.1 | 89.8 | 77.6 | 25.2 | 76.1 |
| Mean (fertilized) | 79.6 | 30.7 | 98.9 | 89.2 | 28.6 | 87.1 |
| LSD (0.05) | NS† | NS | 29.8 | 20.5 | 4.1 | 16.6 |

†NS indicates no significant differences at $p = 0.05$.

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# From Science to Farming and to Food Security


From time to time we all come across great comments that strike a chord with our personal feelings on particular subjects of interest. One such comment that recently caught my attention stated …

*"A person may need a doctor, lawyer, architect, and so many other professionals a few times in one's life, but everyone needs a farmer at least three times a day."*

One could probably argue the details of this statement, as most things seem to be debatable these days. But these facts remain: 1) human-kind does best when it can eat a nutritious meal at least three times a day, 2) the great majority of people are not able to produce their own food, and 3) someone else needs to do it for them. Different people would have different views and many seem to blame farming in so many ways, but I see the realities above as absolutely logical.

It is not wise, in our time of growing technology and knowledge, to ignore the advice of specialists when seeking a better quality of life. Farmers are our food production specialists that, with the right practices supported by science, put food on our tables and keep so many regions food secure.

In the face of criticism, let's give credit to farmers and their mission that is presently supporting over 7 billion people. If this is not a great mission I am not sure what it is!

Luís I. Prochnow
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