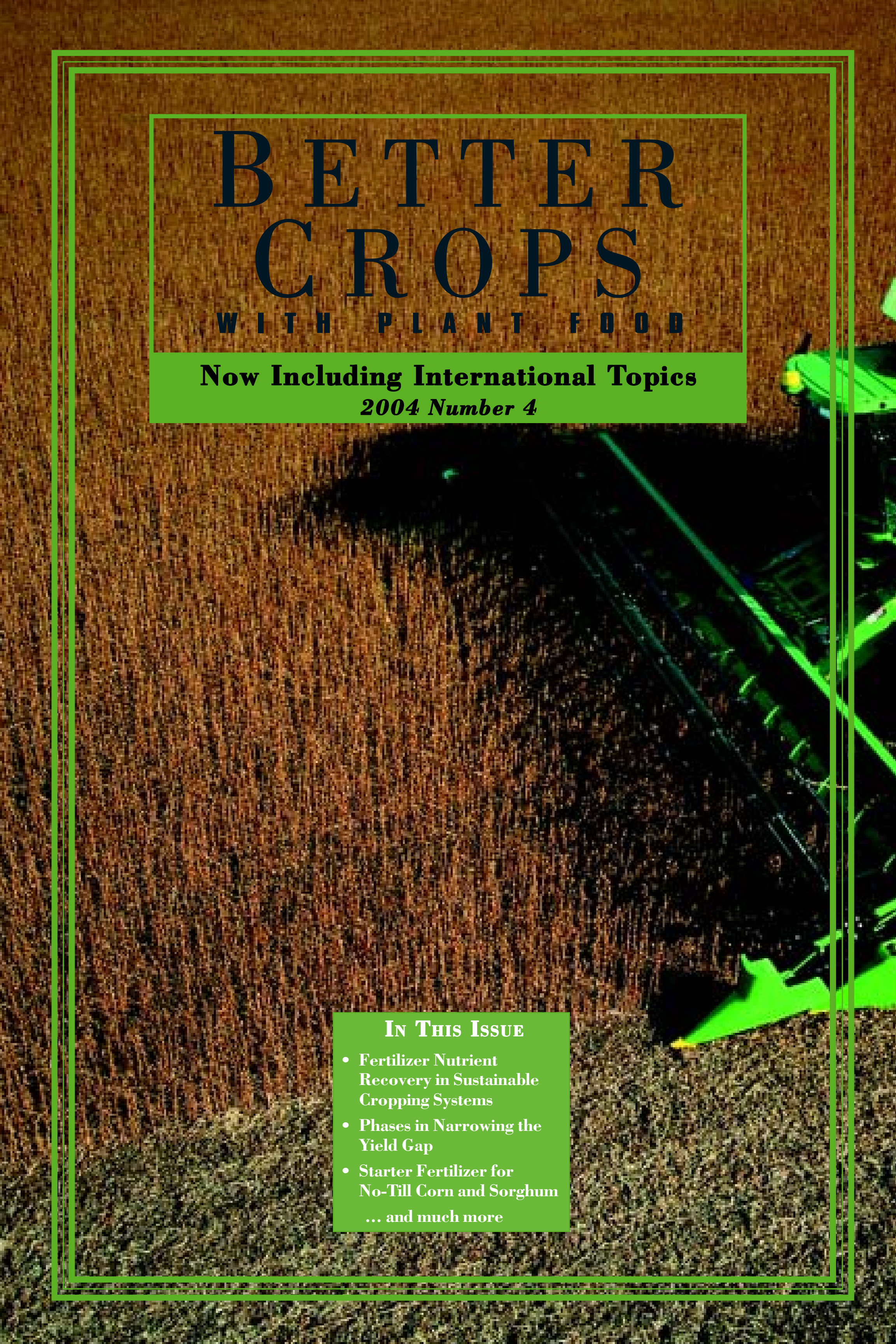

BETTER CROPS
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2004 Number 4

In This Issue

- Fertilizer Nutrient Recovery in Sustainable Cropping Systems
- Phases in Narrowing the Yield Gap
- Starter Fertilizer for No-Till Corn and Sorghum

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Phases in Narrowing the Yield Gap

By Paul E. Fixen

Growers who achieve record-setting yields challenge research scientists and farmers to study how those successes can be replicated in other locations and cropping systems. Observing the practices of high yield growers through the lens of scientific principles can be revealing and lead to researchable questions. Modern technologies can facilitate the process of answering these questions. But major yield improvement requires a willingness to risk changing the way things have always been done.

As we observe how research scientists and farmers often approach this challenge, recognition of phases in yield improvement might be helpful. **Table 1** presents four possible phases and the likely yield benefit and risk level of each.

The first phase is to fully implement standard agronomic best management practices (BMPs) on a site-specific basis. These are well proven practices and so minimal agronomic and economic risk is involved. However, since individuals serious about the challenge at hand are likely to be using BMPs already, yield gains from this phase are likely to be minor.

The second phase is to experiment with optimization of sets of easily controlled production factors. Because the level of one factor can influence response to others, multiple factors must be varied simultaneously. Because of the more complicated nature of such evaluations and uncertainty, more risk is involved, but yield gains may be greater as well.

Table 1. Yield benefit and risk associated with yield improvement phases.

Phase	Yield benefit and risk
Fully implement standard agronomic **site-specific BMPs**	Lower
Experiment with optimizing **sets** of easily controlled factors with the potential to increase yields	↓
Experiment with **system-level** changes, then re-optimize factors	↓
Long-term soil quality improvement with continuous re-optimization of factors as soil properties change	Higher

Phase three involves evaluation of system-level changes like tillage, row-spacing, crop rotation, etc. These are harder still to evaluate so risk is higher, but we take another step up in the potential for yield payback. A change in the system may require re-optimization of the factor levels focused on in phase two.

The final phase has the largest potential impact on yield because crops benefit from the accumulating beneficial effects of past high yields: greater carbon fixation and, as a result, higher soil organic matter levels and improved tilth and water holding capacity. Improved subsoil properties and an associated improved root system may also result. Risk is also high because we do not know if the system being implemented will cause these positive long-term trends until it is in place for several years. As soil properties change, production factors will likely need to be re-optimized.

Thinking in terms of yield improvement phases makes it apparent that a portion of a farm's yield gap can likely be closed in just a few years. A larger portion is likely to require long-term dedication …and patience. BC

Dr. Fixen is PPI Senior Vice President, North American Program Coordinator, and Director of Research, based at Brookings, South Dakota; e-mail: pfixen@ppi-far.org.

Starter Fertilizer for No-Till Corn and Sorghum Production

By Charles S. Wortmann

Starter fertilizer increased both irrigated and dryland corn yields. Yield increases were greater in irrigated than in dryland production. Results from sorghum trials did not support the use of starter at normal planting dates, but response may be greater for early planting dates when soils are cooler.

Starter and pop-up fertilizers are usually applied in addition to other required nutrients to achieve optimal crop growth and performance. Placing a concentrated band of fertilizer near or with the seed often promotes rapid and uniform growth, especially when the soil is cool and wet.

Although the terms are sometimes used loosely, "starter" usually refers to fertilizer applied (at planting) below and to the side of the seed, while "pop-up" or "in-furrow" refers to fertilizer applied with the seed, and "dribble" refers to that applied in a concentrated band on the soil surface. These are all forms of "banding" fertilizer. **However, the term "starter" is sometimes used in reference to all three methods.**

Past research in Nebraska on medium and fine-textured soils under conventional tillage did not find the use of starter fertilizer to be economical. Results of some studies in other states have shown a higher probability of corn and sorghum response to nitrogen (N), phosphorus (P), and sulfur (S) in starter fertilizer under no-till compared to tilled conditions. Furthermore, some studies have found method of placement of starter fertilizer to be important. Also, soil type and topographic position may be important factors determining response.

Fourteen corn trials were conducted in eastern Nebraska in 2002 and 2003 to determine corn response to starter, pop-up, and dribble-applied fertilizer under no-till conditions. Of the fourteen corn trials, eight were located on farmer fields, three at Haskell Lab, and three at the University of Nebraska Lincoln Agricultural Research and Demonstration Center (UNL ARDC). Sites were selected to represent diverse soils and topographic positions.

Twelve sorghum trials were conducted in eastern Nebraska over the same period (2002 and 2003 seasons) to determine sorghum response to starter, pop-up, and dribble-applied fertilizers under no-till conditions. All trial sites were on farmer fields, and were selected to represent diverse soils and topographic positions. Sites were planted at the same time farmers planted, usually in late May.

Eight starter fertilizer treatments for both corn and sorghum were compared. Nitrogen and P starter treatments were compared to a no starter control, and included three methods of application

Table 1. Starter treatments.

lb/A			
N	P_2O_5	S	Starter placement
0	0	0	Control
20	20	0	2 x 2[1]
20	20	0	Over the row
10	10	0	In-furrow
20	20	10	2 x 2
20	20	10	Over the row
10	10	5	In-furrow
10	10	5	In-furrow with ATS[2]

[1]2x2 = 2 in. to side of row and 2 in. deep.
[2] ATS = ammonium thiosulfate.
Ammonium sulfate (AS) is S source in other treatments.

and S rate and source variables. **Table 1** lists treatment details.

Results

Corn. Soil pH in the corn sites ranged from 5.4 to 6.8 (**Table 2**). Soil organic matter (SOM) ranged from 1.9 to 3.3%. Bray-1 P ranged from low to very high, with the median level over three times higher in the 0 to 2 in. depth than in the 2 to 8 in. depth. The potassium (K) level was high or very high at all sites.

On average, corn yield increased 7.5 bu/A with starter fertilizer, with a slightly greater increase with in-furrow placement of N+P as compared to other starter application treatments (**Figure 1**). Response was greater under irrigated conditions (**Figure 2**) than under dryland conditions, although several of the dryland trials experienced severe water deficits. Most of the response occurred at sites where soil Bray-1 P was <15 parts per million (ppm)...**Figure 3. This suggests that P in the starter fertilizer is more important than N.**

Over all trials, there was no benefit to including S in the starter fertilizer (**Figure 1**), but there was a small advantage to including S for dryland sites (**Figure 2**). There was no difference between ATS and ammonium sulfate effect on corn yield.

Sorghum. Sorghum grain yield was increased with starter fertilizer in only one of the 12 trials. The average yield without starter fertilizer was 91 bu/A and the average yield with the most effective starter fertilizer treatment (10 lb N + 10 lb P_2O applied in-furrow) was 93 bu/A. Including S in the starter did not result in increased sorghum yield.

Table 2. Soil test results for 14 trial sites for evaluation of corn response to starter fertilizer treatments.

	pH	SOM, %	K, ppm	P, Bray-1, ppm 0 to 2 in.	P, Bray-1, ppm 2 to 8 in.
Minimum	5.4	1.9	194	4.5	3.1
Maximum	6.8	3.3	621	78.5	33.6
Median	6.0	2.5	312	35.0	9.6

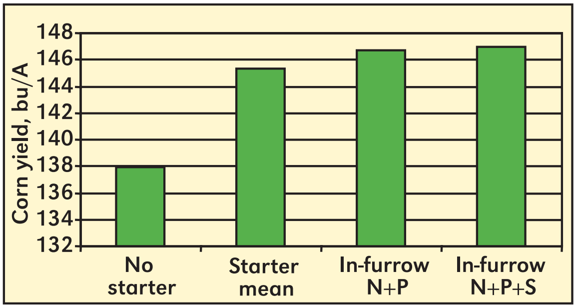

Figure 1. Average corn response to starter fertilizer (irrigated and dryland).

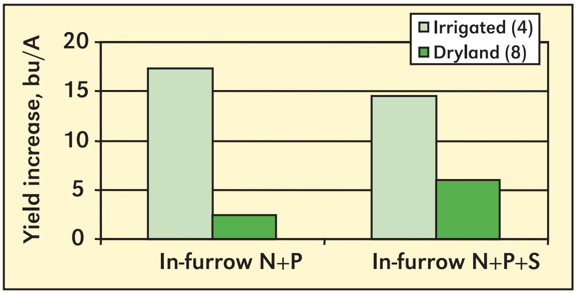

Figure 2. Average corn response to in-furrow fertilizer in irrigated and dryland conditions.

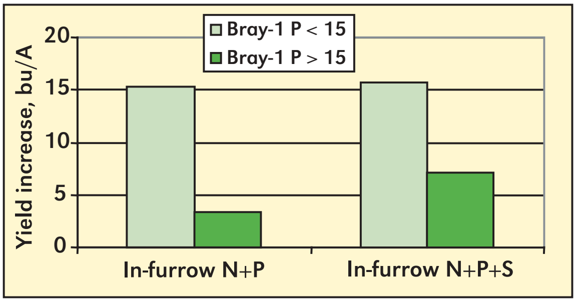

Figure 3. Average corn yield response to in-furrow fertilizer at different soil P levels (bu/A).

Phosphorus was the most important nutrient in starter fertilizer for corn in a Nebraska no-till study.

Conclusion

Corn yield increase under irrigated conditions in Nebraska, especially if soil P is less than 15 ppm, is sufficient to justify application of P and maybe some N in starter fertilizer (e.g., 10-34-0 or 11-52-0) at about 10 lb P_2O_5/A. Yield increases with starter fertilizer under dryland conditions were smaller and less frequent, but starter fertilizer use may be profitable in adequate rainfall years. In-furrow placement was more effective than over-the-row or 2x2 placement.

Based on the results of the 12 sorghum trials, we cannot recommend starter fertilizer for no-till milo (grain sorghum) at the typical planting dates used in Nebraska. Response to starter fertilizer may be greater with earlier planting dates when the soil is cooler. Three trials are continuing in 2004 with an early May planting date at adequate P sites to test the effect of in-furrow application of 10-34-0 as well as the effects of row-cleaning. BC

Dr. Wortmann is Assistant Professor, Department of Agronomy and Horticulture, University of Nebraska-Lincoln; e-mail: cwortmann2@unl.edu.

Revised PowerPoint Slide Set Supplements PPI Soil Fertility Manual

A compact disk (CD) presenting concepts and illustrations from the popular *Soil Fertility Manual* is now available from PPI. The CD includes more than 390 images in PowerPoint format, following the subjects of chapters in the manual.

The *Soil Fertility Manual,* first published in 1978, was revised and updated in 2003. The manual and slide set present basic, practical information under the following subject headings:

Chapter 1, Concepts of Soil Fertility and Productivity; Chapter 2, Soil pH and Liming; Chapter 3, Nitrogen; Chapter 4, Phosphorus; Chapter 5, Potassium; Chapter 6, The Secondary Nutrients; Chapter 7, The Micronutrients; Chapter 8, Soil Sampling; Chapter 9, Soil Testing, Plant Analysis and Diagnostic Techniques; Chapter 10, Fertilize for Profits; Chapter 11, Plant Nutrients and the Environment.

"The content of the CD enables an instructor or someone preparing a presentation to blend in their own local images with the general concepts and subject matter of these slides," says Dr. Terry Roberts, PPI Vice President, Communications and Member Services. "Our hope is that the CD will be useful in many different settings to facilitate learning and better understanding of soil fertility."

The CD (Item #82-6500) is now available for purchase at $50.00 each (English only), plus shipping. The printed manual is sold separately. To order, contact: Circulation Department, PPI, 655 Engineering Drive, Suite 110, Norcross, GA 30092-2837. Phone (770) 825-8082; fax 770-448-0439. E-mail: circulation@ppi-far.org. Or visit the website at: >**www.ppi-ppic.org/ppistore**<.

Phosphorus Fertilization Improves Quality of Stockpiled Tall Fescue

By Dale G. Blevins, Matt Massie, and Will McClain

Previous fescue forage nutrition studies have shown that adequate phosphorus (P) improves forage production, enhances forage magnesium (Mg) uptake, and lowers the risk of grass tetany. Continued research showed that stockpiled forage P and Mg levels declined during the winter, but 57 lb of P_2O_5/A kept stockpiled forage P and Mg levels within desirable ranges for beef cow nutrition. This P rate also boosted hay production by the equivalent of two big round bales/A, resulting in an estimated net return of $30/A.

Missouri is second in the U.S., after Texas, in feeder calf production. Beef cattle production in Missouri and in a large portion of the U.S. is based on tall fescue pastures. Half of the feeder calves in Missouri are produced within a 100-mile radius of the University of Missouri Southwest Research Center near Mt. Vernon. Tall fescue in southwest Missouri is typically grown on soils low in plant-available P.

The major expense of beef cattle production is feeding costs, primarily in harvesting, storage, and consumption of hay. Therefore, it is often recommended that cattle producers save some tall fescue pasture for winter grazing, called "stockpiling", to reduce winter feeding costs.

Early studies in Kentucky, Tennessee, and West Virginia indicated that stockpiled tall fescue contained low P and Mg concentrations. In fact, by late winter and early spring, concentrations of these two nutrients were often below levels recommended for lactating beef cows. This poses a problem for beef herds that calve in late winter and early spring.

Our studies in Southwest Missouri have shown that P fertilization of low P soils increased both P and Mg concentrations of tall fescue leaf tissue in early spring and greatly increased total forage production. That work was conducted to try to increase the Mg concentrations of tall fescue leaves, in order to combat grass tetany in beef cattle. Our new studies on the quality of stockpiled tall fescue included P treatments to improve the nutritional quality of stockpiled tall fescue during winter.

A Stockpiled Tall Fescue P Study

An established Kentucky 31 tall fescue pasture was selected at the Southwest Center near Mt. Vernon on a Creldon soil (mesic Oxyaquic Fragiudalf) that contained 7 lb P/A (Bray 1) and 247 lb Mg/A (ammonium acetate). Triple superphosphate (0-46-0) was applied to 10 ft. x 25 ft. plots at 0, 12.5, and 25 lb P/A (0, 28.5 and 57 lb P_2O_5 /A). Each treatment was replicated 18 times in the 2-year experiment. The study was started the third week in August by

Broomsedge encroachment into tall fescue pasture not treated with P fertilizer is shown at left, compared to pasture at right which received P fertilization.

cutting and removing all forage, then applying the P fertilization treatments. Beginning in mid-October and continuing through April, 20 of the most recently collared leaves were harvested each month. Hay was harvested during the third weeks of May and August. Leaf and hay samples were analyzed for macronutrient element concentrations and these concentrations were compared to those required for diets of lactating beef cows.

Leaf P in Stockpiled Tall Fescue

Leaf P concentrations dropped during the fall and winter months, reaching their lowest levels by mid-February (**Figure 1**). By January of the first year, P levels in leaves from all P treatments were below those required by lactating beef cows, and these P levels remained below 0.20% through mid-April. During the second year, leaves from untreated plots remained between 0.10 and 0.15% P, much lower than levels required for lactating beef cows. However, with the 25 lb P/A applied during a second season, leaf P concentrations remained around 0.20% throughout the winter. At the 12.5 lb P/A treatment level, leaves harvested during December, January, and February of the second year remained below the 0.20% P target level. It should be noted that leaf P concentrations dropped during the second year, although not as dramatically as in the first year. Our working hypothesis is that leaves of this perennial grass translocate or move P to roots during late fall and winter. This is called nutrient remobilization, and involves nutrient transport in phloem tissue.

Leaf Mg in Stockpiled Tall Fescue

In earlier work, we found that late winter P treatments increased tall fescue leaf Mg concentrations during March and April. Based on these studies, we think that tall fescue growing on low P soils has a problem with Mg uptake by roots and Mg transport from roots to leaves. So, we were interested in the response of Mg to P treatments in stockpiled tall fescue.

A decline in leaf Mg concentration occurred during late fall and winter, reaching the lowest levels in mid-March (**Figure 2**). This decline was very similar to the decline in leaf P concentrations, except P levels were lowest in mid-February. A sharp decline in Mg concentration also occurred during the second year, but with the 25 lb P/A treatments, leaf Mg concentrations remained about 0.20%. Again, our hypothesis is that this mobile divalent cation, Mg, is re-translocated during late fall and winter months from leaves to roots. Magnesium concentrations in leaves of untreated tall fescue dropped below the 0.20% target in January, February, and March of both years, indicating a nutritional problem for early calving beef cows.

Leaf Potassium (K) and Calcium (Ca) in Stockpiled Tall Fescue

Leaf K concentrations declined each fall and winter. However, leaf K concentrations did respond to the P treatments

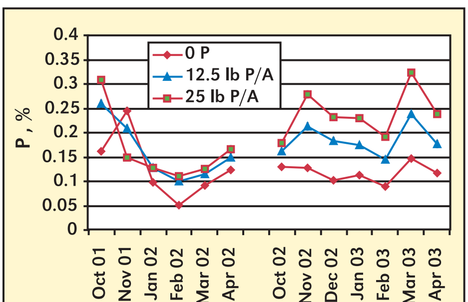

Figure 1. Leaf concentrations of P following P fertilization of stockpiled tall fescue.

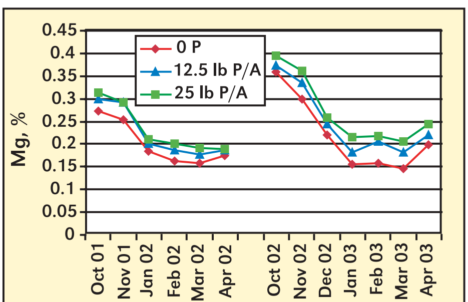

Figure 2. Leaf concentrations of Mg following P fertilization of stockpiled tall fescue.

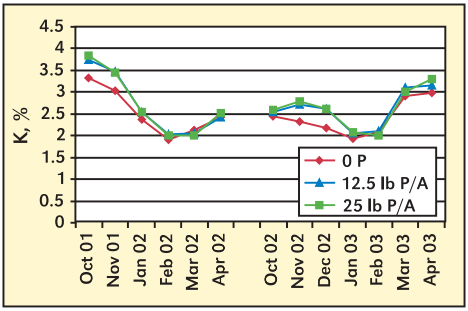

Figure 3. Leaf concentrations of K following P fertilization of stockpiled tall fescue.

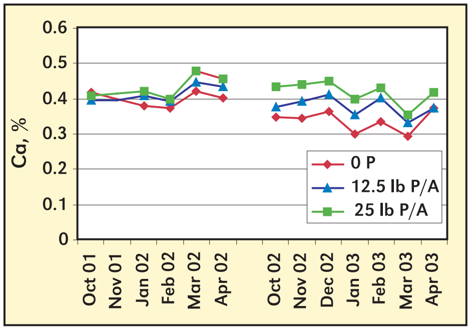

Figure 4. Leaf concentrations of Ca following P fertilization of stockpiled tall fescue.

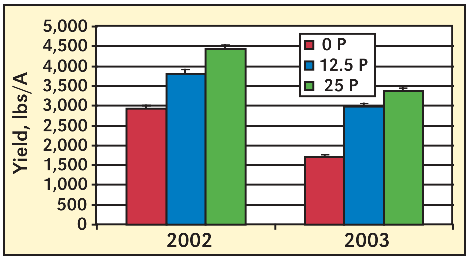

Figure 5. Hay yield of tall fescue treated with P fertilization. Hay was harvested in May and August of each year.

Note: In **Figures 1-5,** 12.5 lb P/A = 28.5 lb P_2O_5; 25 lb P/A = 57 lb P_2O_5

(**Figure 3**). The K levels of leaves from all treatments exceeded the nutrient requirements for lactating beef cows.

Calcium is not mobile in phloem tissue in plants, and therefore is not remobilized from leaves to roots during winter. Thus it was not surprising to find that Ca concentrations in leaves remained level during late fall and winter (**Figure 4**). During the second year, there was an obvious Ca response to the P treatments, with leaves from the 25 lb P/A treatment being higher than those from the 12.5 lb P/A treatment. Leaves from both P treatments were higher in Ca than from untreated control plots.

Hay Production and P Treatments

As we have reported in the past, P fertilization at this location increased tall fescue hay production by over 1,500 lb/A/year (**Figure 5**). This yield increase is equivalent to about two big round bales of hay. At $25 per bale, this would equal $50/A of increased hay production as a result of P fertilization. Fertilizer for 25 lb P/A (57 lb P_2O_5) would cost around $15.45, so the net (minus application cost) return on investment would be around $30/A. For a forage production system, it is not uncommon to harvest tall fescue yields totaling 4 t/A/year, either by grazing or by hay harvests, and based on our results, this would remove about 16 lb P/A or 37 lb P_2O_5 /A.

Conclusions

The physiological nature of tall fescue may affect the quality of stockpiled tall fescue during the winter months. Leaf P and Mg concentrations declined during late fall and winter, and research is underway to determine if these mobile elements are retranslocated from leaves to roots as winter approaches. By late winter, both P and Mg levels dropped below those required for lactating beef cows, unless plots were treated with 25 lb P/A. This P application rate boosted hay production by the equivalent of two big round bales, or by a net return of about $30/A, at a cost of $15.45 for the P fertilizer. It would also reduce the amount of supplemental Mg required by the grazing beef cows. BC

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PPI/FAR Research Project MO-15F

GEORGIA

Chloride Requirements in Onion: Clarifying a Widespread Misunderstanding

By William M. Randle

Chloride (Cl) is a misunderstood nutrient. Recent studies in Georgia have found that onions require higher levels of Cl than previously thought. The reason is related to stomates, which regulate movement of gases in and out of plant leaves.

In most plants, Cl is an essential minor element which is thought to be toxic at high concentrations. There has been extensive research on Cl requirements by wheat, barley, corn, and sorghum, showing sufficiency levels in the 0.15 to 0.40% range. Talk with tobacco farmers in south Georgia about applying high rates of Cl to fields and you just might find that Southern hospitality has a limit, and it stops at Cl. Tobacco burning quality is affected by Cl...the crop is extremely sensitive to even moderate levels, as growers know.

However, in southeastern Georgia, tobacco is not king. The onion is. This is the home of the well-known "Vidalia®" onion. Grown in the sandy soils of the Coastal Plain, these onions are internationally known for their sweet and mild flavor. We have observed that higher plant potassium (K) levels are often associated with higher sugar levels in onion and the percentage of good bulbs is associated with higher phosphorus (P) nutrition.

Onions also have a high requirement for Cl, which is not well known. The problem arises because many onion producers also grow tobacco, and they are concerned about elevated soil Cl.

Preliminary research at the University of Georgia has shown that onions not only tolerate high Cl levels, but may actually require these higher levels for optimum growth and production. When Cl was supplied at high levels…up to 500 parts per million (ppm) in nutrient solutions…several studies by our group have shown that Cl, on average, is the fourth most utilized essential element, superceded only by nitrogen (N), K, and P. **Figure 1** illustrates the relative uptake of nutrients.This result is amazing considering Cl is thought to be required by plants in only small amounts.

The reason for the high Cl requirement of onions may reside in the plants' stomates. The stomates are structures on the leaf surface which regulate the movement of gases in and out of the leaf. Specialized cells, called guard cells, either swell or deflate, which opens or closes a leaf pore, thereby regulating movement of gases

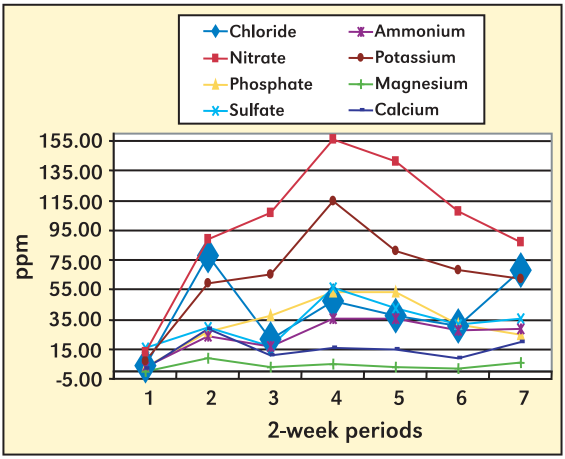
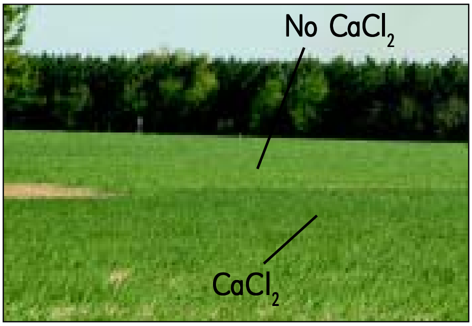


Figure 1. Usage patterns for selected nutrients in onion during growth, development, and maturation. Chloride nutrient usage is highlighted.

Plant stomates on the leaf have kidney-shaped guard cells surrounding the circular pore. In onion plants, K^+ and Cl^- ions control the opening and closing of the pore.



The effects of adding 20 lb Cl/A to onion fields in south Georgia. Plants which received Cl application through irrigation water have healthier, darker green foliage.

in and out of the plant. In most plants, K^+ ions (+ charged) move in and out of guard cells, and cause stomates to open or close (see above).

The positively charged K^+ ions need to be balanced by a negatively charged ion, usually malate, formed from the decomposition of starch. Onions do not have starch, so they have evolved a different mechanism to counter the influx of positively charged K^+ ions by utilizing the negatively charged Cl^- ion. Knowing this, it stands to reason that Cl is needed in high amounts to produce an onion crop. Unfortunately, the Cl requirement is not widely known among the onion community. Some claim that onions are sensitive to Cl. Based on our preliminary work, this is not the case.

Chloride fertilization in onion is also overlooked and avoided because of an often misinterpreted association with sodium. Current recommendations for onion production in Oregon, Michigan, New York, Georgia, Texas, and California call for no additional Cl to be added to fertilization programs. If Cl status in the plant is compromised, poorly functioning guard cells can lead to a number of abnormalities, including reduced photosynthesis (which may lower yields) and reduced transpiration. This can lead to water "congestion" and increased foliar disease. Recent observations and analyses in commercial onion fields suggest that a low Cl status may have an association with a higher disease incidence. Elevated Cl levels have reduced disease severity in several grasses and potato. Most recently, it has reduced *Stemphylium vesicariium* disease in pears.

Soils in Georgia were recently tested for Cl levels prior to planting onions. Most results indicated that extractable Cl was present at less than 6 lb/A, which is the lower limit of detection. In an effort to evaluate the effects of adding Cl to the fertility program, several test areas were established. The effects of adding 20 lb Cl/A can be seen in the field photo above. The onion plants in the foreground received Cl through the irrigation water and are darker green than the onions in the background. The effects of Cl fertilization on onion production and quality in these two areas are still being investigated. As we learn more about Cl, the recommended rate for Cl fertilization will likely increase.

In summary, research into effects of Cl on onion production is just beginning. Preliminary trials indicate that onions would benefit from increased Cl fertility in Georgia. Our current research is exploring Vidalia® onion yield and pungency response to Cl, Cl effects on disease reduction, and effects of late K application on sugar content, onion quality and calcium uptake and utilization. Other onion-producing areas should consider testing to determine Cl levels in their soils and fertilize accordingly. BC

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PPI/FAR Research Project GA-27F

Nitrogen, Phosphorus, and Potassium Fertilizer Management for Oats

By R.M. Mohr, C.A. Grant, and W.E. May

Oat yield was optimized when soil plus fertilizer nitrogen (N) was at 90 to 100 lb/A. Response to phosphorus (P) and potassium chloride (KCl) was minor in these trials.

Oat production in the northern Great Plains has increased in recent years. Production on the Canadian prairies currently accounts for more than half of the total Canadian oat crop and exports.

Despite the growing prominence of oats in today's production systems, limited research on fertilizer management for oats has been conducted in this region. Fertilizers often account for a significant proportion of total input costs in cereal production systems, and may strongly influence crop growth, development, yield, and quality. Moreover, improved fertilizer management of oats may help to enhance crop quality and thus the potential for producing high-quality oats that are suitable for more specialized milling and horse feed markets offering price premiums.

A 3-year field study was initiated in 2000 with the objectives of determining the effect of N, P, and KCl on the growth, yield, and quality of oats, and to determine the impact of varying combinations of the nutrients. Field experiments were established at two sites in the area of Brandon, Manitoba. One site was located on a Newdale clay loam containing low levels of soil nitrate-N (NO_3-N) and extractable-P. The second site was located on a Stockton fine sandy loam or Wellwood loam soil containing low levels of soil NO_3-N and higher extractable-P levels, but considered marginal based on soil test results.

Experimental treatments consisted of a factorial combination of four N rates (0, 36, 72, 108 lb N/A as urea), three P rates (0, 27, 54 lb P_2O_5/A as monoammonium phosphate [MAP]), and two potassium (K) rates (0 and 36 lb K_2O/A as KCl). Each treatment received an additional 12 lb N/A as urea or MAP in addition to the N rate indicated, to account for N supplied by the highest P rate. An unfertilized control treatment was also included. Oats (cv. AC Assiniboia) were direct-seeded using a plot seeder equipped with hoe openers on 9 in. row spacing. At time of seeding, urea and KCl were sidebanded and MAP was placed with the seed. Grain yield was determined by straight-combining the entire plot, and oat test weight, kernel weight, and percentage of plump kernels were determined.

Soil test nutrient levels at the trial sites ranged from low to medium for N (8 to 15 parts per million [ppm] in the top 24 in.), low to sufficient for P (4 to 15 ppm P in top 6 in.), and medium to sufficient for K (113 to 246 ppm K in top 6 in). Soil nutrient analysis used an extraction with $NaHCO_3$. Nitrate-N was determined by hydrazine reduction, P (PO_4) was by molybdate/ascorbic acid, and K was by atomic absorption. Grain yield responses were expected for N and P, while no response was expected for K.

Low rates of fertilizer N were found to increase oat grain yields at all locations, with the crop response leveling off or declining at higher rates. While maximum oat yield was typically attained at the 36 to 72 lb N/A rate, the optimum relative yield was achieved with a total of soil + fertilizer N of approximately 90 lb N/A

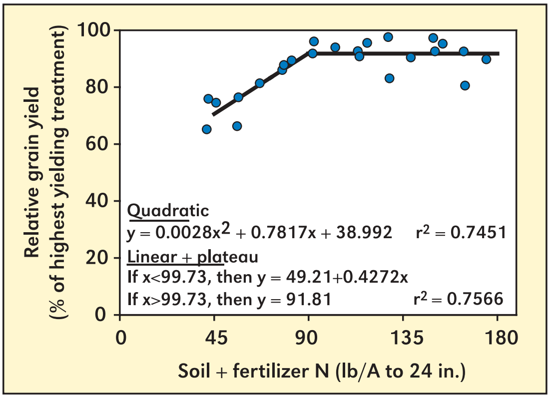

Figure 1. Effect of soil NO_3-N level (to 24 in. deep) plus fertilizer N on relative yield of oats at six field sites. (Treatments not receiving P were not included in the calculation of the means.)

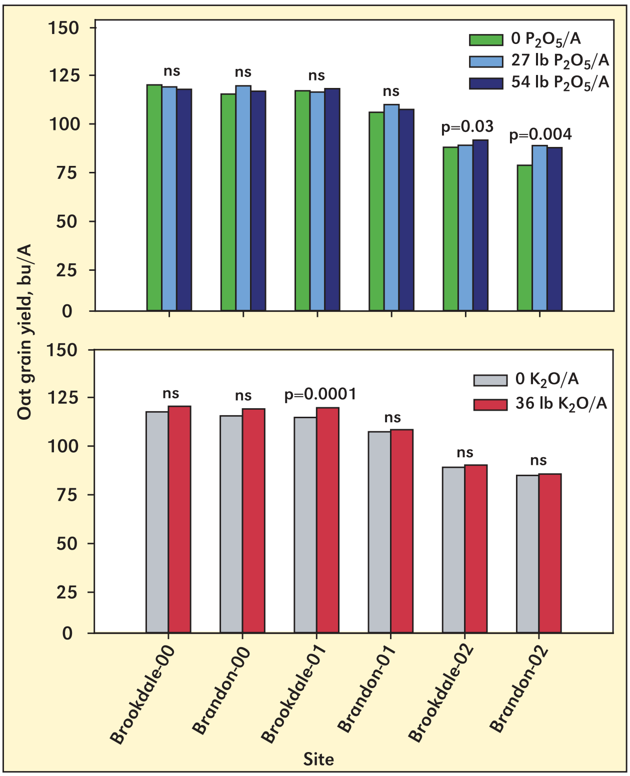

Figure 2. Oat grain yield in reponse to P and K application; mean of all N rates. (Note: ns indicates that differences among treatments within a site were not statistically significant at p=0.05.)

(**Figure 1**). In this study, optimum yields ranged from 90 to 135 bu/A of oats. Nitrogen additions had the most consistent impact on the grain quality of the oat crop. Increasing N rates always resulted in a small but significant decline in oat test weight, kernel weight, and the percentage of plump kernels for both trial locations and all years.

Phosphorus application was found to increase oat grain yield at two of the six trial site-years (**Figure 2**). This occurred despite increased early season crop biomass yield at tillering with P application at both sites and all years (data not shown). In addition, plant development assessment showed that P application significantly advanced the developmental stage of the main stem and tillers arising from the coleoptile (T0) and the first leaf (T1). The observed crop response to fertilizer P application did not appear to be closely linked to soil test P levels. The response to P addition in 2002 may reflect the very dry spring soil moisture conditions, reducing the availability of soil P to plants and contributing to the positive crop response to fertilizer P. No consistent grain quality effects were observed with the application of P fertilizer to the oat crop.

Potassium fertilizer use was found to provide a small but statistically significant oat grain yield increase at one of the six trial locations (**Figure 2**). While a similar trend was observed at the two locations in 2000, these were not significant. The use of KCl increased the plumpness of oat kernels at three of the six locations (data not shown). The test weights of oats were also increased at one of the six locations, and decreased at another. While significant, these grain quality differences were relatively small in magnitude. While interactions among nutrients applied occurred in a number of instances, there was no strong or consistent pattern.

The results of this study support previous research indicating that oats remove less nutrients per bushel of production than many of the other crops grown on the northern Great Plains. Nutrient removal in oats is approximately 0.5 to 0.8 lb N/bu, 0.23 to 0.28 lb P_2O_5/bu, and 0.17 to 0.20 lb K_2O/bu. While fertilizer N additions increased oat yields, application in excess of rates required to optimize yield should be avoided to maintain grain quality. Fertilizer P additions improved early season plant development, at all locations, and grain yield at two of the six trials. Potassium fertilizer application resulted in small improvements in both oat yield and quality.

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PPI/FAR Research Project MB-21F

InfoAg 2005 Set for July 19 to 21, InfoAg Midsouth February 7 to 9

The popular Information Agriculture Conference series returns July 19 to 21, with **InfoAg 2005 in Springfield, Illinois**. For veterans of the conferences as well as newcomers, the program will feature the latest in precision farming practices, data analysis from yield monitors and field geographic information systems (GIS), communications tools, and information management. A large exhibit hall and hands-on computer workshops are planned.

A special, regional **InfoAg Midsouth** conference is planned for February 7 to 9, 2005, in Tunica, Mississippi. Targeting innovative consultants and farmers, the program will concentrate on technology and information management for cotton, rice, and soybean production systems. Much of the program will be built around individuals sharing their experience, with updates on new technology and research from universities and industry, geared to real-world applications.

Additional information is available at these websites:

>**www.farmresearch.com/infoag**< or >**www.ppi-far.org**<.

FAR Involved in Soybean Rust Focus

Asian soybean rust in South America is the focus of a new project sponsored by the Institute for Technology Development, National Aeronautics and Space Administration. The Foundation for Agronomic Research (FAR) will coordinate assistance in collecting ground measurements to be used in interpreting remote sensing imagery. The Brazilian government research organization (EMBRAPA) and U.S. aerospace companies will also cooperate.

"The goal is to develop an early warning and tracking system for the disease…to help manage it in Brazil and in the U.S., if it eventually comes to this country," explains Dr. Harold F. Reetz, President of FAR.

For more about this and other FAR programs, contact Dr. Reetz.

E-mail >**hreetz@ppi-far.org**<.

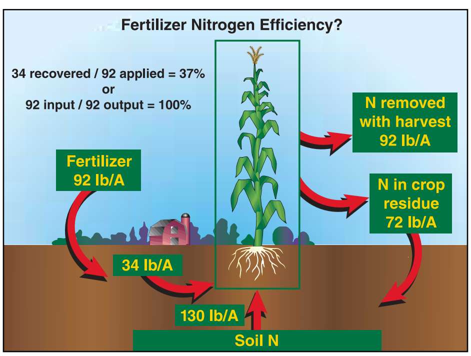
Fertilizer Nutrient Recovery in Sustainable Cropping Systems

By T.W. Bruulsema, P.E. Fixen, and C.S. Snyder

While single-year crop responses often recover less than half the nutrients applied as fertilizers, cropping systems are more efficient. Nutrient additions support the maintenance of soil organic matter and fertility as well as crop yields.

Current estimates of recovery efficiencies for nitrogen (N), phosphorus (P), and potassium (K) fertilizers used in North American crop production vary considerably. They vary largely because of differences in definition. Recovery by the crop's response differs from recovery by the cropping system.

Recovery efficiency is defined as the amount of nutrient in the crop as a ratio of the amount applied or available. Its calculation varies widely depending on the system being considered: the soil-plant system, the whole plant, the above-ground portion of the plant, or the harvested portion of the plant may be considered the vessel of recovery. The inputs may or may not include: applied manures, mineralization of soil nutrients, atmospheric deposition, and contribution of soil micro-organisms, in addition to applied fertilizers. Recovery can be calculated for each single source or for the total of all sources.



Fertilizer N efficiency is influenced by long-term dynamics of a soil's organic matter.

Recovery from a single source is often estimated from the single-year response: the difference in nutrient uptake between fertilized and unfertilized plants. It can also be measured using tracers. Both methods are subject to error.

Error arises in the difference method because plants respond to nutrient deficiencies by altering root growth and the capacity of roots to acquire nutrients. These mechanisms may not be operative in—or compatible with—the type of plant growth associated with the higher yield levels of fertilized plants.

Recovery estimates using tracers are confounded by internal cycling of nutrients in the soil. For example, the rapid uptake and release of ammonium and nitrate forms of N (mineralization-immobilization turnover) generally reduces the concentration of the tracer in the N made available to plants.

A recent study measured the difference between N uptake in fertilized and unfertilized plots in 55 producer-managed corn fields in the north central U.S. (Cassman et al., 2002). Recovery of N in above-ground plant biomass averaged only 37% of fertilizer N applied. This is a disturbingly low figure. Assuming a typical N harvest index (portion of above-ground N in grain) of 56%, it implies that as little as 21% of the fertilizer N applied is removed in the grain. In actual practice, this level of efficiency would be difficult to match, since optimum rate was selected in hindsight from a rate study. Where is the rest of the fertilizer going?

Let's look more closely at the meaning of 37% recovery in this example. What it means is that in these fields, when fertilizer was added at an optimum rate (which averaged 92 lb/A), it boosted the uptake of N into the above-ground portion of the plant by 34 lb/A (37% of 92).

The fertilized corn took up an average of 164 lb N/A: 130 from the soil and 34 from the fertilizer. The total amount of N in its grain would be 56% of 164 = 92 lb/A: equal to the amount of fertilizer applied. So is the recovery 21% (as estimated by single-year-response recovery in grain) or 100% (assuming the observed balance of input and output is sustainable long-term)?

The answer cannot be known unless the longer-term dynamics of the soil's organic matter are understood. If the cropping system is maintaining organic matter, and if the 130 lb/A of N from the soil came from mineralization of organic matter, an equivalent amount of N must be returned in the form of crop residues, and also stabilized to protect it from loss.

If the soil is gaining organic matter, even more N is required. The crop converted at least 164 lb/A of mineral N into organic forms; more if below-ground assimilation by roots and associated microflora is considered. How much will be held in that form depends on the dynamics of decomposition, controlled to some degree by tillage management.

Mineralization of N from soil organic matter is a large but unsustainable source for the replacement of crop removal. Depletion of organic matter eventually reduces the productivity of soils. In a sustainable cropping system, N contributed by mineralization needs to be returned to rebuild soil organic matter. Crop residues—exudates, roots, and stover—return this N.

In recent years, through a combination of reduced tillage and the return of increased residues from higher-yielding crops, many areas have reversed the trend of organic matter decline. Since 1970, soils of the central U.S. Corn Belt are sequestering N at the rate of 20 lb/A/year as their organic matter increases through reduced tillage (Lal et al., 1998). As conservation tillage expands, requirements for N can be expected to increase, and part of the reason is that a source of N is needed for soil organic matter accumulation.

Table 1. Soil organic carbon (SOC) accumulated from 1965 to 1995 in the top foot of a soil cropped to continuous corn.

Applied N, lb/A/yr	SOC derived from corn tons/A	%
150	7.6	21
75	5.8	17
0	4.5	12

Source: Wilts et al., 2004

Nitrogen boosts the return of crop residue to the soil and enhances its conversion to stable soil organic matter. Many experiments have shown that fertilizing crops with N results in higher levels of soil carbon over time. An example from Minnesota is shown in **Table 1**. Paustian et al. (1997) documented 20 sites worldwide that gained soil carbon (C) in response to application of N fertilizers over periods ranging from 7 to 120 years. As shown in **Figure 1**, N is integral to the chemical structure of soil organic matter, and is stabilized within it.

The conversion of N into organic forms by plants and associated soil

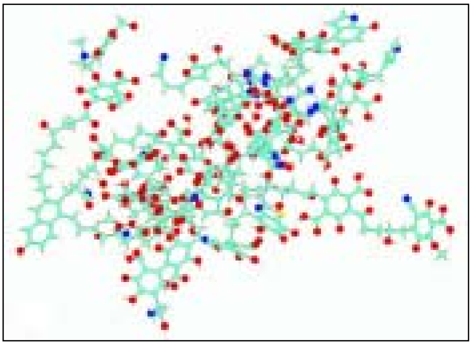


Figure 1. Chemical structure of soil organic matter (Schulten and Schnitzer, 1997). The element colors are: N-blue, C-cyan, hydrogen-white, oxygen-red, sulfur-yellow.

microflora gives the mobile nutrient N properties similar to the relatively immobile nutrients P and K. Recovery of all three nutrients is greater in the long term than in the short term. While single-year-response recovery of fertilizer P often ranges from 15 to 25%, longer-term recovery in cropping systems is more typically 50 to 60%, and for some systems as high as 70 to 90% (Smil, 2000).

Among the producer-managed fields described above, five had single-year-response recovery efficiencies in excess of 60% even when fertilized at rates of 160 lb N/A or more. This suggests that high rates of nutrient application can be compatible with high recovery efficiencies.

A study in France reported recovery of 71% of labeled fertilizer N in corn, with 26% of the remainder recovered as soil organic N and only 3% as inorganic forms subject to losses.

Recent data for U.S. corn suggest that the harvested grain removes amounts equivalent to 81, 122, and 77% of the N, P and K applied as fertilizers. Removals relative to applications have increased significantly in recent decades (**Figure 2**).

Removal by all North American crops relative to nutrients supplied in the form of fertilizers and manures amounts to 95% and 143% for P and K, respectively. The comparable figure for N is 77%, but considering non-legume crops only, it declines to 64%. The lower recovery for N could be taken as an indication of priority for

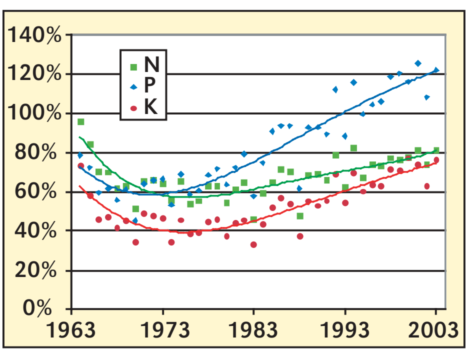


Figure 2. Grain nutrient removal as percentage of fertilizer use on corn in the U.S.

efforts at enhancement, or more thorough documentation of its role in contributing to increased soil organic matter. Appropriate management of P and K can contribute to improved N recovery.

Conclusion

Low nutrient recovery in a single-year response does not imply that the remainder is permanently lost. We need to improve short-term response recovery, but not at the expense of long-term sustainability. Nutrient inputs to cropping systems have important roles in supporting the maintenance of soil organic matter and fertility, in addition to directly supporting crop yield. **Enhancement of use efficiency of nutrients must be integrated with that of all resources essential to sustainable crop production.** BC

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References

Cassman, K.G., A. Dobermann, and D.T. Waters. 2002. Agroecosystems, nitrogen use efficiency, and nitrogen management. Ambio 31(2), 132-140.

Lal, R., J.M. Kimble, R.F. Follett, and C.V. Cole. 1998. The SOC pool in U.S. soils and SOC loss from cultivation. *In* The potential of U.S. cropland to sequester carbon and mitigate the greenhouse effect. Ann Arbor Press, Chelsea, MI. 128 p.

Paustian, K., H.P. Collins, and E.A. Paul. 1997. Management controls on soil carbon. p. 39-41, Chpt. 2. *In* E.A. Paul, K. Paustian, E.T. Elliot, C.V. Cole (eds.) Soil Organic Matter in Temperate Agroecosystems, CRC Press, Inc.

Schulten, Hans-Rolf, and Morris Schnitzer. 1997. Chemical model structures for soil organic matter and soils. Soil Science 162(2):115-130.

Smil, V. 2000. Phosphorus in the environment: natural flows and human interferences. Annu. Rev. Energy Environ. 25:53-88.

Wilts, A.R., D.C. Reicosky, R.R. Allmaras, and C.E. Clapp. 2004. Long-term corn residue effects: harvest alternatives, soil carbon turnover, and root-derived carbon. Soil Sci. Soc. Am. J. 68:1342–1351.

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International Section

INDIA

Site-Specific Nutrient Management for Maximum Economic Yield of the Rice-Wheat Cropping System

By Arvind K. Shukla, V.K. Singh, B.S. Dwivedi, S.K. Sharma, and K.N. Tiwari

The rice-wheat cropping system (RWCS) in India accounts for about one-third of the area of both rice and wheat grown in South Asia and provides staple food grain for more than 400 million people or about 8% of the world's population. This paper discusses a field-specific nutrient management approach that has been adopted as a strategy capable of assuring restoration of soil fertility and sustaining high yields.

Of the 12.5 million hectares (M ha) of estimated area managed under RWCS in South Asia, India alone accounts for 10 M ha. Because RWCS is the most widely practiced annual crop rotation in India, and both component crops are staple food grains, a sustained high productivity of RWCS is necessary for national food security. For over a decade, RWCS yields have either stagnated or declined, particularly in high productivity zones. The most important reason is a decline in factor productivity resulting from depletion of soil fertility and emergence of multiple nutrient deficiencies.

Recent surveys in the Upper-Gangetic Plain zone revealed that farmers apply greater than recommended doses of both nitrogen (N) and phosphorus (P), but ignore the replenishment of other nutrients. Such an unbalanced use of fertilizer not only aggravates the deficiency of potassium (K), sulfur (S) and micronutrients in the soil, but it also proves uneconomic and environmentally unsafe. The high yield potential of modern varieties can never be exploited with inadequate and unbalanced fertilization. Site-specific nutrient management (SSNM), considers indigenous nutrient supply of the soil and productivity targets as a strategy to provide sustained high yields on one hand, and assure restoration of soil fertility on the other.

The positive effect of SSNM on rice productivity was related to higher number of grains/panicle, grain weight/panicle, and other factors.

Materials and Methods

A field experiment at Project Directorate for Cropping System Research experimental station, Modipuram, Meerut, was conducted during 2002-03 on a Typic Ustochrept sandy loam soil located in western Uttar Pradesh. The soil is very deep (more than 2 m), well drained, and Gangetic alluvium. The experiment was comprised of 12 treatments (**Table 1**).

Table 1. Treatment details for on-station experiments.

Treatments	Rice							Wheat		
$SSNM_1$	N_{170}	P_0	K_{120}	S_{20}	Zn_7	Mn_{17}	$B_{0.6}$	N_{150}	P_0	K_{120}
$SSNM_2$	N_{170}	P_{30}	K_{120}	S_{20}	Zn_7	Mn_{17}	$B_{0.6}$	N_{150}	P_{30}	K_{120}
$SSNM_3$	N_{170}	P_{30}	K_{80}	S_{20}	Zn_7	Mn_{17}	$B_{0.6}$	N_{150}	P_{30}	K_{80}
$SSNM_4$	N_{170}	P_{30}	K_{40}	S_{20}	Zn_7	Mn_{17}	$B_{0.6}$	N_{150}	P_{30}	K_{40}
$SSNM_5$	N_{170}	P_{30}	K_0	S_{20}	Zn_7	Mn_{17}	$B_{0.6}$	N_{150}	P_{30}	K_0
$SSNM_6$	N_{170}	P_{30}	K_{120}	S_{20}	Zn_7	Mn_{17}	B_0	N_{150}	P_{30}	K_{120}
$SSNM_7$	N_{170}	P_{30}	K_{120}	S_{20}	Zn_7	Mn_0	$B_{0.6}$	N_{150}	P_{30}	K_{120}
$SSNM_8$	N_{170}	P_{30}	K_{120}	S_{20}	Zn_0	Mn_{17}	$B_{0.6}$	N_{150}	P_{30}	K_{120}
$SSNM_9$	N_{170}	P_{30}	K_{120}	S_0	Zn_7	Mn_{17}	$B_{0.6}$	N_{150}	P_{30}	K_{120}
LAR	N_{150}	P_{75}	K_{75}	–	Zn_5	–	–	N_{150}	P_{60}	K_{60}
STLR	N_{180}	P_{55}	K_{55}	–	Zn_5	–	–	N_{180}	P_{45}	K_{45}
FP	N_{180}	P_{60}	–	–	Zn_5	–	–	N_{180}	P_{60}	–

The SSNM recommendation for a yield target of 10 t rice grain/ha was 170 kg N, 120 kg K_2O, 20 kg S, 17 kg manganese (Mn), 7 kg zinc (Zn), and 0.6 kg boron (B)/ha. These nutrients, in order, were applied as urea, muriate of potash, gypsum, zinc sulfate, manganese sulfate, and sodium tetraborate. As the soil was high in available P, a maintenance dose of 30 kg P_2O_5/ha was applied as diammonium phosphate (DAP) in treatments $SSNM_2$ to $SSNM_9$. Healthy 25-day-old seedlings of hybrid rice cv. PHB 71 were transplanted on July 26 during 2002 and the crop was harvested on November 6, 2002. Wheat (cv. PBW 343) was sown on November 28, 2002, on the same layout with the applications of NPK, only to assess the cumulative applications of NPK and carryover effect of secondary and micronutrients. The crops were grown under irrigation with adoption of a recommended package of cultural practices. The economics of various fertilizer treatments were determined using total cost of crop cultivation, plus cost of different operations performed and inputs.

Yield and Yield Attributes

Rice: Fertilizer application according to the SSNM schedule for treatment $SSNM_2$ resulted in the highest rice grain yield of 9.95 t/ha, whereas farmer practice (FP) produced the lowest yield of 7.29 t/ha (**Table 2**). For the treatments $SSNM_2$ to $SSNM_5$ receiving varying K rates from 0 to 120 kg K_2O/ha, a statistically significant ($p<0.05$) increase in yield was recorded with incremental rates up to 80 kg K_2O/ha. Compared with the zero-K control, the treatment receiving 80 kg K_2O/ha gave 0.97 t/ha additional rice yield. Fertilizer K applied beyond 80 kg K_2O/ha did not produce more yield. Interestingly, the yield differences between zero-K and 40 kg K_2O/ha treatments were non significant, which indicated that on K-deficient soil, a high yielding genotype may not respond to sub-optimal K fertilization rates. This may also explain the non significant response to K applied as per state recommendation in many other studies.

Treatments omitting either S or micronutrients resulted in a marked yield loss, indicating the significance of replenishment of these nutrients for achieving high yield targets. Compared with $SSNM_2$, yield reductions were 0.48 t/ha (-B), 0.95 t/ha (-Mn), 1.24 t/ha (-Zn), and 2.03 t/ha (-S).

Although the treatments receiving fertilizers according to local ad-hoc recommendation (LAR) or state soil-testing laboratory

Table 2. Yield and yield attributes of hybrid rice as influenced by site-specific nutrient management practices.

Treatment	Grain yield, t/ha	Yield attributes: Number of panicles/m^2	Number of grains/panicle	Grain weight/panicle, g	Number of unfilled grains/panicle
$SSNM_1$	9.86	198	180	5.30	29
$SSNM_2$	9.95	215	176	5.34	32
$SSNM_3$	9.72	201	182	5.22	29
$SSNM_4$	9.18	210	167	5.09	31
$SSNM_5$	8.75	210	147	4.66	37
$SSNM_6$	9.47	206	171	4.92	42
$SSNM_7$	9.00	190	165	4.89	42
$SSNM_8$	8.71	193	156	4.76	47
$SSNM_9$	7.92	196	142	4.52	47
LAR	8.03	190	133	4.12	40
STLR	7.94	188	138	4.30	42
FP	7.29	193	128	4.08	49
CD *($p<0.05$)*	0.51	11	8	0.17	5

recommendation (STLR) had significantly higher yields than FP, the best SSNM schedule out-yielded LAR or STLR by about 2.0 t/ha. Straw yields (data not shown) also showed similar treatment behaviors, although the differences were not as sharp as in case of grain yield. Balanced fertilization resulted in a greater harvest index.

The positive effect of SSNM on rice productivity was the cumulative increase measured in different yield-contributing characters. Whereas number of panicles/m^2 remained largely unaffected by fertilizer management options, parameters like number of grains/panicle and grain weight/panicle were significantly greater in SSNM treatments compared with those under FP, LAR, or STLR. Balanced fertilization also increased grain filling in the panicles and had fewer unfilled grains/panicle (29 to 32), as recorded in $SSNM_1$ to $SSNM_4$, compared with FP, LAR, or STLR, or SSNM treatments not receiving a secondary or micronutrients.

Wheat: The grain yield of wheat grown on the same experimental treatment layout, but without the application of secondary and micronutrient, was also the highest (5.94 t/ha) with the $SSNM_2$ treatment, and the lowest (4.53 t/ha) using FP (**Table 3**). As in rice, wheat responded to K application up to 80 kg K_2O/ha, and in treatments receiving K beyond 80 kg K_2O/ha there was no yield benefit. Yields of treatments receiving no P ($SSNM_1$) and 30 kg P/ha ($SSNM_2$) were statistically comparable, but yield difference was wider as compared to rice.

Table 3. Yield and yield attributes of wheat (2002-03) as influenced by site-specific nutrient management.

Treatment	Grain yield, t/ha	No. of ears/m	No. of grains/ear	Grain wt/ear
$SSNM_1$	5.71	249	40	1.78
$SSNM_2$	5.94	254	49	1.96
$SSNM_3$	5.78	255	48	1.90
$SSNM_4$	5.34	248	45	1.62
$SSNM_5$	5.06	248	40	1.48
$SSNM_6$	5.36	252	42	1.60
$SSNM_7$	5.28	255	42	1.68
$SSNM_8$	4.98	238	38	1.68
$SSNM_9$	4.59	217	34	1.65
LAR	4.86	205	36	1.56
STLR	4.62	216	38	1.52
FP	4.53	218	39	1.44
CD *($p<0.05$)*	0.31	29	4	0.22

The magnitude of residual effect of secondary and micronutrient ranged between 0.46 t/ha to 1.35 t/ha. Omitting S or micronutrients from the SSNM package caused marked yield reductions. Omitting S reduced yield by 1.35 t/ha. Among the micronutrients, omission of Zn had the largest impact followed by B and Mn. Application of fertilizer following LAR

Table 4. Net profit (US$/ha) as influenced by site-specific nutrient management in the rice-wheat system (2002-03), Uttar Pradesh.

Treatment	Total cost of cultivation	Total Net return	Increase over FP	Increase over STLR	Increase over LAR	Increase over K_0	Increase over B_0	Increase over Mn_0	Increase over Zn_0
$SSNM_1$	739	1,126	462	374	367	199	117	131	249
$SSNM_2$	797	1,135	471	384	377	208	126	141	259
$SSNM_3$	782	1,103	439	352	345	176	94	109	227
$SSNM_4$	766	998	334	247	240	71	-11	4	122
$SSNM_5$	750	927	263	176	169	0	-82	-67	51
$SSNM_6$	791	1,009	345	257	250	82	0	15	132
$SSNM_7$	768	994	330	243	236	67	-15	0	118
$SSNM_8$	786	877	212	125	118	-51	-132	-118	0
$SSNM_9$	785	735	70	-17	-24	-193	-274	-260	-142
LAR	810	759	94	7	0	-169	-250	-236	-118
STLR	775	752	87	0	-7	-176	-257	-243	-125
FP	776	664	0	-87	-94	-263	-345	-330	-212
CD *($p<0.05$)*	–	93	–	–	–	–	–	–	–

or STLR out-yielded FP, but $SSNM_2$ produced 1.08 t/ha and 1.32 t/ha more, respectively.

Economics

The total costs of the rice-wheat system under the SSNM options were very narrow and ranged between US$750 to 797/ha. However, a great difference in total net return was recorded under SSNM and FP, with corresponding values of US$1,135 and 664/ha, respectively (**Table 4**). The highest net return was obtained with the $SSNM_2$ treatment. Among the SSNM treatments 2 to 5 the profitability increased with increasing doses of K_2O, but it became non-significant beyond 80 kg/ha K_2O. Omission of K in SSNM application schedule resulted in 22% and 19% decline in net profitability over its 120 or 80 kg K_2O application rate. The decrease in net income resulting from omitting secondary nutrients and micronutrients ranged between US$126 to 400/ha. Omission of S caused the highest loss in profitability, followed by Zn, Mn, and B. Interestingly, omission of K or application of 40 kg K_2O in a SSNM schedule caused a negative impact on profitability, even with balanced application of secondary and micronutrients, indicating that their full potential is not possible without adequate K. **The economic profitability of the LAR and STLR were similar, but significantly better than FP. Net returns with LAR/STLR were about US$375/ha under $SSNM_2$.** BC

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Attaining High Yield and High Quality Banana Production in Guangxi

By Tan Hongwei, Zhou Liuqiang, Xie Rulin, and Huang Meifu

Small improvements in high value plantation crop production can generate very large economic benefits to farmers. Field trials indicate that conventional nutrient management practices greatly limit the profitability of banana production systems in southwest China. Potassium (K) is a key nutrient in higher yields and quality.

Guangxi's sub-tropical climate is well-suited to the production of many tropical fruits. Of these, banana has received the most attention, resulting in a rapid transformation of the planted area. In 2003, 60,000 hectares (ha) of banana were planted in the province. Extensive cultivation with rather poor nutrient management has resulted in low yields and poor fruit quality. Average yields range between 18 to 20 t/ha, or approximately one-third the level attained under optimal management practices.

Banana's large biomass, and its high concentration of K in the fruit, are factors responsible for the crop's large annual demand for K. Biomass production ranging between 80 to 200 t/ha requires 290 to 1,970 kg K_2O/ha. Soils growing banana in Guangxi are usually acidic, light to medium textured, and deficient in K. Present soil testing surveys indicate available K ranges between 75 and 155 mg/kg.

The objective of this study was to determine proper application rates for K and other nutrients for optimal banana production systems. A replicated field experiment conducted in the Nanning suburb of Jilin Town compared farmer practice against five treatments supplying combinations of one rate of nitrogen (N), two rates of phosphorus (P), and four rates of K (**Table 1**). The farmer practice treatment relied on low N and K inputs, moderate use of P fertilizer and a significant quantity of farmyard manure (FYM) applied once as a basal application. Treatments provided all the P at planting while N and K fertilizers were split eight times, supplying 4% basally, and 9%, 11%, 17%, 18%, 18%, 12%, and 11% during the other seven dressings spaced throughout the growing season. Researchers planted *Villains* cv., a high yielding, tissue-cultured variety, at 1,920 plants/ha.

Effect of P and K on Growth and Yield

Differences in plant height or stem diameter were not obvious across treatments (**Table 2**). However, the effect of K was large for all NPK treatments, including farmer practice, which produced more fruit fingers per plant and higher single fruit weights compared to the NP treatment. Number of fingers per plant, and particularly, single fruit weight varied considerably amongst NPK treatments. Finger number was not

Guangxi Province produces about 60,000 ha of bananas, but yields ranging from 18 to 20 t/ha are about one-third of the potential.

Potassium increased single fruit weight, yield, and banana quality.

Table 1. Plant nutrients applied (kg/ha) to banana grown in Jilin Town, Nanning, Guangxi.

Treatments	N	P_2O_5	K_2O	Manure[†]	$N:P_2O_5:K_2O$
1. NP_2K_0	1,016	355	0	0	1: 0.4: 0
2. NP_2K_1	1,016	355	916	0	1: 0.4: 0.9
3. NP_2K_2	1,016	355	1,375	0	1: 0.4: 1.4
4. NP_2K_3	1,016	355	1,832	0	1: 0.4: 1.8
5. NP_1K_2	1,016	177	1,375	0	1: 0.2: 1.4
6. Farmer practice	530	288	576	9,600	1: 0.6: 1.1

[†]Farmyard manure content: 0.32% N, 0.25% P_2O_5, 0.36% K_2O

Table 2. Treatment effect on banana growth characters, Guangxi.

Treatments	Plant height, cm	Stem diameter, cm	Fruit fingers per plant	Single finger weight, g
1. NP_2K_0	230.5	58.6	153.3	80.0
2. NP_2K_1	234.5	61.5	166.6	98.3
3. NP_2K_2	232.8	60.8	164.0	120.7
4. NP_2K_3	233.4	61.0	163.9	124.8
5. NP_1K_2	234.4	61.6	163.2	92.7
6. Farmer practice	235.0	61.0	161.3	89.6

Table 3. Treatment effect on banana yield, Guangxi.

		Yield increase by K			Yield increase by P		
Treatments	Yield, t/ha	t/ha	%	kg/kg K_2O	t/ha	%	kg/kg P_2O_5
1. NP_2K_0	23.6	–	–	–	–	–	–
2. NP_2K_1	31.2	7.6	32	8.3	–	–	–
3. NP_2K_2	38.0	14.4	61	10.5	8.7	30	48.9
4. NP_2K_3	39.3	15.7	66	8.6	–	–	–
5. NP_1K_2	29.3	5.7	24	–	–	–	–
6. Farmer practice	27.7	4.1	17	–	–	–	–

strongly influenced by K rate, although single fruit weight showed a strong, positive relationship to increased K supply. The impact of P supply was especially large as a 50% reduction in application rate resulted in a 23% reduction in single fruit weight.

Farmer practice also produced relatively low single fruit weight. This treatment provided fewer nutrients in the form of fertilizer, but considerable amounts of N, P, and K as FYM. Considering the nutrient concentrations of the manure sources, the overall macronutrient input for farmer practice had 45% less N, 12% less P, and 67% less K than the most effective NPK treatment NP_1K_2. This indicates the substantial impact of imbalanced nutrition on yield when fertilizer inputs are not matched to FYM nutrient content and crop demand.

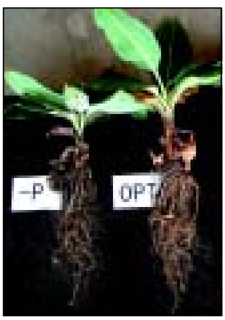
Table 4. Effect of K fertilizer on banana fruit quality, Guangxi.

Treatment	NP_2K_0	NP_2K_1	NP_2K_2	NP_2K_3
Vitamin C, mg/kg	7.9	8.7	8.7	8.8
Soluble sugar, %	13.6	14.3	14.2	14.8
Edible portion, %	58.4	62.6	62.9	64.0

Plant growth improvements mirrored banana yield response. Final fruit yield increased with K fertilization rate. Thus, the highest K rate of 1,832 kg K_2O/ha produced a maximum yield of 39.3 t/ha, which was 66% higher than the zero K control and nearly 42% higher than farmer practice (**Table 3**). The next lowest K rate, at the same level of P input (treatment 3), produced 1.3 t/ha less than the maximum. Yields were cut another 8.7 t/ha (30%) by reducing P input 50% (i.e., treatment 5 vs. treatment 3).

Yields and single fruit weight were low with the nutrients provided by normal farmer practice.

Optimal rates of N-P_2O_5-K_2O for banana production were determined to be 1,016-355-1,832 kg/ha.



Optimum fertilization produced a better root system than the minus P (-P) treatment.

Table 5. Economic analysis (US$/ha) of treatments applied to banana, Guangxi.

Treatment	NP_2K_0	NP_2K_1	NP_2K_2	NP_2K_3	NP_1K_2	Farmer practice
Fertilizer input[1]	743	1,001	1,129	1,258	1,051	711
Other input[2]	966	966	966	966	966	966
Total input	1,709	1,967	2,095	2,224	2,017	1,677
Total income[3]	5,976	7,911	9,639	9,956	7,436	6,030
Net income	4,267	5,944	7,544	7,732	5,419	4,353
Net income increase vs. K_0	-	1,677	3,277	3,464	1,152	86
Net income increase, %	-	39	77	81	27	2

[1]Fertilizer cost US$/kg: N = 0.58, P_2O_5 = 0.44, K_2O = 0.28; farmyard manure = 0.01
[2]Other inputs included seedlings, labor, pesticides, etc.
[3]Banana prices, US$/kg: improved = 0.25; farmer practice = 0.22

Effect of K Fertilizer on Fruit Quality

Potassium had a pronounced effect on the vitamin C content of the fruit, although differences amongst K supplying treatments were not significant (**Table 4**). Soluble sugar content showed a similar trend although advantages to the highest K application rate were more apparent. The edible portion of fruit clearly increased with K application rate, which is consistent with the observations for single finger weight. Specific observations included increased length, breadth and surface area of fruit, and decreased banana peel weight.

Economic Analysis

The economic benefit from balanced nutrient management was highly significant (**Table 5**). Besides the larger fruit inventories resulting from higher yields, any improvement in fruit quality garnered farmers a higher market price per unit. Treatment 4, with the largest P and K input, generated the highest net income of US$7,732/ha. That was 81% above the zero K control and 78% higher than farmer practice. A 25% reduction in K input (treatment 3) generated a marginally lower net income of US$7,544/ha. We reason that the further addition of 457 kg of K_2O to increase banana yield by 1,300 kg and net income by $188 (equal to 2.8 kg banana and $0.41 for each extra kg of K_2O added) is justified based on the small land holdings per farm and the overriding need to maximize farm income. The 50% reduction in P input (treatment 5 vs. treatment 3) generated a much less desirable effect as profits were 30% higher under the high P, mid K treatment.

Banana growth, yield, and quality response to P and K highlight major limiting factors to maximum economic yield for plantations in Guangxi. Optimal application rate was determined to be 1,016-355-1,832 kg N-P_2O_5-K_2O/ha, which should be generally recommended to growers in the province unless specific soil test data indicate otherwise. BC

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Effect of Balanced Fertilization on Pulse Crop Production in Red and Lateritic Soils

By S.S. Bhattacharya, Debkanta Mandal, G.N. Chattopadhyay, and K. Majumdar

Considering the potential for improving the productivity of pulses, an effort was made to assess the effects of proper nutrient management on yield levels and associated yield characteristics of greengram and blackgram in red and lateritic soils.

In India, pulses are mostly cultivated on marginal soils under rainfed situations with minimum external nutrient input. Farmers often fail to apply essential nutrients. The result is very low crop yields—the current average hovers at about 700 kg/ha. Whatever is spent on fertilizer goes almost entirely to nitrogen (N). Thus, pulse crop production has become non-remunerative and has left a large gap between domestic requirement and actual production. Despite the importance of pulses in the human diet and production advantages gained from including a legume in the crop rotation, pulse production in West Bengal is failing to maintain pace with population growth. For a population of 80 million people, the pulse requirement is 1.2 million metric tons (M t). With current production at 220,000 t, the opportunity for improving the productivity of pulses through efficient nutrient management is great.

Red and lateritic soils are major soils in the state of West Bengal. Crop productivity levels are usually low, owing to various soil related constraints such as low pH, organic matter, and nutrient availability. Rice is the major summer, wet season crop. However, inclusion of a short duration pulse crop holds promise for increasing and sustaining productivity of these soils through biological N fixation and reduced disease via crop rotation. Being deep rooted, they use moisture efficiently from lower soil strata.

Materials and Methods

An on-farm field experiment, conducted to assess the effect of balanced fertilization on the performance of greengram (*Vigna radiata*) and blackgram (*Vigna mungo*), was established at Bolpur on a typical red and lateritic soil. The soil had 0.62% organic carbon (C) and the available N, phosphorus (P), and potassium (K) contents were 312, 19, and 101 kg/ha, respectively. Available boron (B) and molybdenum (Mo) were considered low. Seven treatments included: a zero fertilizer control ($N_0P_0K_0$), recommended rates of 20 kg N, 40 kg P_2O_5, and 40 kg K_2O/ha applied as N, NP, NPK, NPK plus 10 kg borax/ha, NPK plus 1 kg ammonium molybdate/ha, and the complete NPKBMo treatment. Greengram variety Pusa Baishakhi and blackgram variety Kalindi (B-76) were grown

Table 1. Different growth parameters of greengram and blackgram in response to test treatments, West Bengal.

Treatments	Plant height, cm 60 DAS	Dry weight, g/m^2 60 DAS	Crop growth rate, $g/m^2/day$ 40-60 DAS
		Greengram	
$N_0P_0K_0$	44.7	325.2	8.9
NP_0K_0	48.7	341.2	9.3
NPK_0	52.6	346.0	9.3
NPK	54.5	360.8	9.4
NPKB	56.3	371.1	9.6
NPKMo	59.5	380.6	9.5
NPKBMo	63.7	397.8	9.5
SEm (±)	0.7	0.6	0.04
C.D. (p=0.05)	2.3	1.9	0.1
		Blackgram	
$N_0P_0K_0$	24.9	175.6	5.4
NP_0K_0	25.4	183.4	5.4
NPK_0	27.7	190.4	5.6
NPK	28.6	202.6	6.1
NPKB	30.5	215.3	6.3
NPKMo	33.9	225.6	6.6
NPKBMo	37.7	233.3	6.8
SEm (±)	0.7	0.8	0.1
C.D. (p=0.05)	2.1	2.3	0.1

during the pre-monsoon season in two separate randomized blocks with similar management practices.

Results and Discussion

The data on plant height, dry matter production, and crop growth rate (CGR) of the two crops are presented in **Table 1**. The complete NPKBMo treatment produced significantly higher plants than any other treatment at 60 days after seeding (DAS). Similar results were found for dry matter production in both crops. Treatments having a co-application of macronutrients and micronutrients tended to have enhanced CGR values.

After 5 weeks of growth, the Mo-containing treatments produced much better plant chlorophyll than the NPK or NPKB treatments (**Table 2**). Since Mo is a prominent constituent of nitrate reductase, the presence of adequate N along with Mo

Table 2. Chlorophyll, root nodule, and yield components of greengram and blackgram in response to test treatments, West Bengal.

Treatments	Chlorophyll content, mg/g, total	No. of nodules/plant 5 Weeks	Nodule dry weight/plant, mg 5 Weeks	Test weight, g	No. of pods/plant	No. of seeds/pod
			Greengram			
$N_0P_0K_0$	1.173	24.53	18.27	21.29	12.43	7.42
$N_{20}P_0K_0$	1.413	29.33	19.37	22.54	12.45	7.49
$N_{20}P_{40}K_0$	2.454	30.53	20.47	22.67	14.62	8.23
$N_{20}P_{40}K_{40}$	2.648	33.46	24.80	23.50	17.45	9.25
NPKB	2.902	40.27	29.13	23.57	19.21	10.43
NPKMo	3.295	49.00	36.27	23.64	21.47	10.83
NPKBMo	3.724	49.57	39.16	24.01	24.78	10.94
SEm (±)	0.001	0.765	0.673	0.051	0.009	0.021
C.D. (p=0.05)	0.004	2.360	2.074	0.157	0.030	0.064
			Blackgram			
$N_0P_0K_0$	1.301	25.43	13.67	32.97	10.29	2.62
$N_{20}P_0K_0$	1.551	25.50	16.20	33.22	10.41	2.65
$N_{20}P_{40}K_0$	1.915	25.80	18.90	33.43	15.51	3.28
$N_{20}P_{40}K_{40}$	2.191	29.07	21.53	33.49	17.41	4.39
NPKB	2.742	30.33	27.37	33.52	18.39	4.42
NPKMo	3.655	37.70	32.50	33.59	21.19	4.73
NPKBMo	3.786	38.43	35.73	33.73	23.15	4.81
SEm (±)	0.001	0.784	0.358	0.013	0.054	0.018
C.D. (p=0.05)	0.004	2.415	1.104	0.042	0.166	0.054

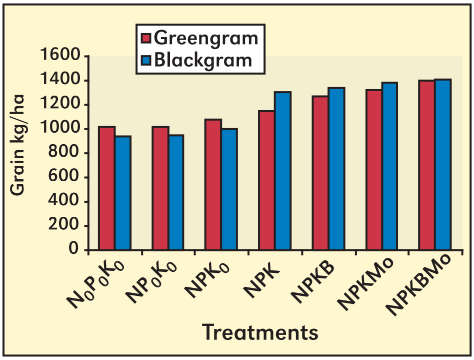

Figure 1. Effect of various treatments on grain yield of greengram and blackgram.

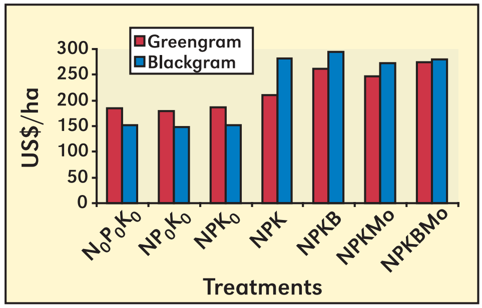

Figure 2. Balanced fertilization improves net profit in blackgram and greengram.

is assumed to enhance the nitrate assimilation rate, and in turn, activate leaf chlorophyll as well as increase the rate of photosynthesis.

Plant root nodulation (numbers and weight) kept pace with plant growth until flower initiation (**Table 2**). The numbers of nodules per plant were highest in the Mo-containing treatments, an expected result due to the known role Mo plays in nodule formation. Despite this, nodule dry weight per plant was greatest in plots which received the complete treatment. Nodules entered their senescence phase 5 weeks after planting. Thus the active period for nodule growth and development is restricted to about one-third of the total growth period.

The grain yield component data presented in **Table 2** show that the numbers of pods per plant and seeds per pod increased steadily as nutrient application became less limiting. The combined benefit is reflected in amounts of harvested grain (**Figure 1**). In both crops, plots receiving no fertilizer or N only exhibited similarly poor yields. Plots treated with the complete NPKBMo treatment returned the highest greengram yield (1,398 kg/ha). A similar yield response was observed in blackgram although the response to micronutrients appeared less prominent.

Balanced application of NPK along with B and Mo will be an effective solution for higher grain yield of pulses in red and lateritic soils. Adequate NPK fertilization increased green and blackgram yields by 13% and 38% over the control. Further inclusion of B and Mo improved yield by 38% for greengram and 50% for blackgram over the control. An economic evaluation of each treatment reveals that the complete treatment was most profitable in greengram (**Figure 2**). However, NPK plus B alone returned the highest profits in blackgram as marginal yield gains obtained with Mo could not support the current added cost. BC

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High Quality Maize Response to Nitrogen, Phosphorus, and Potassium in Jilin

By Xie Jiagui, Zhang Kuan, Wang Xiufang, Wang Lichun, Zhang Guogang, and Yin Caixia

Recently, high oil maize and high starch maize hybrids have been introduced to northeastern China. Gradually, more attention is being given to management practices to boost their performance.

Jilin Province is often considered the "maize belt of China" since the crop accounts for 50 to 60% of its cultivated area. Maize also consumes 65 to 75% of the total amount of commercial fertilizers applied in the province. Although significant scientific and technological achievements have been made regarding the fertilization of maize in Jilin, little fertilization research on high oil and high starch maize has been conducted. This research investigates if and how starch or oil content can be altered in these maize types through specific nutrient applications on Jilin's black soils.

All experimental treatments were arranged in a randomized complete block design with three replications. Plots were 20 m^2 with ridges set at distances of 0.6 to 0.65 m. The soil was characterized as having 2.1% organic matter (OM) and a pH of 5.5. Available soil nitrogen (N), phosphorus (P), and potassium (K) were 113.7, 20.3, and 123.4 mg/kg, respectively. A high oil hybrid, Tongyou 1, was planted at a density of 45,000 plants/ha; the high starch hybrid Zhengdan 21 was planted at 50,000 plants/ha. The fertilizers used were urea, diammonium phosphate (DAP), and potassium chloride (KCl).

The experimental treatments are shown in **Table 1**. All of the P and K and one-fourth of the N were applied at planting, with the remaining N applied as topdressing. The crop was planted in late April and harvested in late September. Plots were hand weeded and disease and insect problems managed with pesticides, as needed.

Potassium deficiency is shown on the right in each of these photos. The hybrids are Zhengdan 21 (high starch) in photo at left and Tongyou 1 (high oil) in photo at right.

Yield and Income Benefit

Nitrogen, P, and K uptake by the two maize hybrids was substantially greater than by hybrids used for normal purposes. The yield increase produced by the balanced NPK application was significantly higher than the treatment without fertilizer in both maize hybrids. However, both the yield increase (2,637 kg/ha or 39.6%) and profit (US$155/ha) in Zhengdan 21 were higher than those realized in

Table 1. Average yield and profit for specialty maize hybrids, Jilin.

$N-P_2O_5-K_2O$, kg/ha	Yield, kg/ha		Yield increase, kg/ha		Net profit, US$/ha	
	Tongyou 1	Zhengdan 21	Tongyou 1	Zhengdan 21	Tongyou 1	Zhengdan 21
0-0-0	5,947	6,665	0	0	0.0	0.0
195-75-90	7,589	9,302	1,642	2,637	52.0	155.4
0-75-90	6,871	8,573	924	1,908	51.6	153.8
195-0-90	6,341	7,667	394	1,002	-54.2	9.0
195-75-0	7,194	8,923	1,247	2,558	31.8	136.8

Tongyou 1 $LSD_{0.01}$ = 1,012, $LSD_{0.05}$ = 696; Zhengdan 21 $LSD_{0.01}$ = 1,312, $LSD_{0.05}$ = 902

Prices: N= US$0.38/kg, P_2O_5 = US$0.31/kg, K_2O= US$0.23/kg, Maize= US$0.10/kg

Tongyou 1 (1,642 kg/ha or 27.6% and US$52/ha) when balanced formulations of NPK fertilizers were applied. The response of the high starch type to N, P, and K was different from the response of the high oil maize hybrid. The salient results are presented in **Table 1** and summarized as follows.

- Under the zero N treatment (0-75-90), both the high oil and high-starch types responded to P and K by significantly increasing yields by 924 kg/ha and 1,908 kg/ha, (15.5% and 28.6%), respectively, as well as profits by US$51.6 and 153.8/ha.
- With the zero K treatment (195-75-0), yields were somewhat lower than, but not significantly different from, the yields obtained with the full NPK treatment. This indicates lesser responses to K, although the effect of omitting K appeared to be greater in the high oil hybrid type. The same trend was evident when considering economic impact of omitting K.
- In the zero P treatment (195-0-90), yield was significantly restricted in Tongyou 1, which resulted in a net loss in income. Although both yield and net profit were comparatively higher in Zhengdan 21, the omission of P had the greatest impact of all the nutrients on yield and profitability.
- The order of impact of N, P, and K, in the various combinations used and for both maize types, was NPK>NP>PK>NK.

Conclusions

The 'fertilizer nutrient susceptible' characteristics were different for high oil and high starch maize. Application of NPK fertilizers had significant yield increase effects on both types. Although omitting either N or K had substantial yield and income reducing effects, they had less impact than the omission of P. The best yields and profits were realized with full and balanced NPK fertilization. The high oil hybrid Tongyou 1 was lower-yielding than the high starch hybrid and was more responsive to N and P than to K, whereas the high starch hybrid was less affected by the omission of K. BC

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Balanced Fertilization Increases Garlic Yield in Anhui

By Li Lujiu, Guo Xisheng, Zhang Qingsong, Xia Hongmin, and Zhang Lin

Field experiments with garlic show that rational use of potassium (K) greatly promoted garlic growth and yield. Balanced fertilization is shown to improve crop value by a large margin, with farm income being enhanced considerably.

A high-yielding garlic crop demands large amounts of nutrients, especially nitrogen (N) and K. Garlic is particularly sensitive to low soil K supply. Based on traditional practice, garlic growers in southeast China tend to rely on fertilizer sources that contain only N and phosphorus (P)—resulting in steadily declining available soil K levels. Potassium uptake imbalance relative to N can predispose the crop to serious disease and insect damage. In addition to loss of garlic shoot and clove yields, crop quality is also lower, reducing the viability of this cash crop alternative. Balanced fertilization technology improves both nutrient management practices by farmers and eliminates the effect of K deficiency on garlic production. Educational activities to promote this practice are being pursued.

This article outlines results from field trials conducted at three sites in Lai'an County, Anhui Province. Soil properties of the top 20 cm of soil are provided in **Table 1**. Six combinations of N and K, applied with 90 kg P_2O_5/ha, were tested at one paddy site in Shuikou and at two sites at Xin'an, one a paddy soil (Xin'an - 1), the other a dryland soil (Xin'an - 2). Fertilizers included urea, diammonium phosphate (DAP), and potassium chloride (KCl). All P and K were applied basally with 60% of the N. The remaining N was topdressed at mid-season. The local variety "Lai'an white garlic" was sown at the end of September at a density of 600,000 plants/ha. Garlic shoots and cloves were harvested in early and late May, respectively.

Potassium had an obvious growth-promoting effect on garlic (**Table 2**). Plant height, number of leaves, stem circumference, the

The effect of K application on garlic... from left to right: zero K_2O application, 150 kg/ha, and 300 kg/ha.

Table 1. Basic soil properties of the three experimental sites, Anhui.

Site	pH	O.M.,%	Available soil nutrients, mg/kg								
			K	N	P	S	B	Cu	Fe	Mn	Zn
Shuikou (1998-1999)	6.2	0.45	58.6	41.9	8.9	49.2	0.06	7.5	133.2	42.9	1.8
Xin'an - 1 (2000-2001)	6.1	0.54	58.7	17.4	5.8	63.0	0.00	3.3	99.0	46.0	1.2
Xin'an - 2 (2000-2001)	6.3	0.51	74.3	30.9	7.0	52.9	0.00	2.0	49.4	27.7	1.0

Table 2. Effect of NPK treatments on growth characteristics of garlic, Anhui.[1]

Treatments[2]	Plant height, cm	Number of leaves	Stem circumference, cm	Shoot length, cm	Shoot diameter, cm	Shoot weight, g	Weight of top growth, g	Clove weight, g
$N_{300}K_0$	77.6	4.30	3.66	39.0	0.47	8.0	46.6	13.0
$N_{300}K_{150}$	88.0	5.16	4.43	59.1	0.64	14.7	68.7	16.0
$N_{300}K_{300}$	91.4	5.23	4.66	64.0	0.69	16.6	80.0	17.5
$N_{375}K_0$	83.3	4.56	3.80	40.8	0.51	9.3	53.6	13.8
$N_{375}K_{150}$	88.6	5.20	4.43	59.0	0.65	14.6	73.5	16.5
$N_{375}K_{300}$	93.2	5.30	4.60	63.8	0.70	15.6	82.0	16.3

[1]The average of the three sites.
[2] Phosphorus was supplied at 90 kg P_2O_5/ha.

length and diameter of garlic bolts, weight of garlic bolts and cloves, and top growth weight per plant substantially increased with N and K. The majority of highest values resulted with N-P_2O_5-K_2O rates of 375-90-300 kg/ha. Field notes indicated that leaf color was more vibrant, plant growth was vigorous and robust, and garlic shoots and cloves were visually larger when K was supplied.

As with crop growth, increasing the K application significantly raised yield (**Table 3**). At Shuikou, under the low N rate, K increased shoot yield by 121 to 156% and clove yield by 45 to 71% compared to the zero K control (farmer practice). Potassium used in combination with the higher N rate produced 103 to 127% higher shoot yields and 11 to 36% higher clove yields. At Xin'an, the range of yield increases for all treatments was 18 to 33% for shoots and 38 to 56% for cloves on paddy soil, and 24 to 29% (shoots) and 35 to 43% (cloves) on dry land.

(continued on page 35)

Table 3. Garlic yield response and economic benefit from NPK application, Anhui.

Site	Treatments[1]	Yield, t/ha Shoot	Yield, t/ha Clove	Yield increase t/ha Shoot	Yield increase t/ha Clove	Yield increase % Shoot	Yield increase % Clove	Income[2] increase, US$/ha
Shuikou	$N_{300}K_0$	2.11	4.53	–	–	–	–	–
	$N_{300}K_{150}$	4.66**	6.55**	2.55	2.02	121	45	647
	$N_{300}K_{300}$	5.39**	7.75**	3.28	3.22	156	71	908
	$N_{375}K_0$	2.31	5.39	–	–	–	–	–
	$N_{375}K_{150}$	4.69**	6.00*	2.38	0.61	103	11	449
	$N_{375}K_{300}$	5.24**	7.35**	2.93	1.96	127	36	699
Xin'an - 1 (Paddy field)	$N_{300}K_0$	6.99	9.30	–	–	–	–	–
	$N_{300}K_{150}$	8.27**	13.1**	1.28	3.84	18	41	666
	$N_{300}K_{300}$	9.15**	14.5**	2.16	5.20	31	56	969
	$N_{375}K_0$	7.50	10.3	–	–	–	–	–
	$N_{375}K_{150}$	9.56**	14.3**	2.06	3.93	28	38	801
	$N_{375}K_{300}$	9.96**	15.3**	2.46	5.00	33	48	946
Xin'an - 2 (Dryland)	$N_{300}K_0$	7.06	10.4	–	–	–	–	–
	$N_{300}K_{150}$	8.80**	14.0**	1.74	3.63	25	35	714
	$N_{300}K_{300}$	9.10**	14.8**	2.04	4.40	29	43	858
	$N_{375}K_0$	7.46	11.4	–	–	–	–	–
	$N_{375}K_{150}$	9.26**	15.5**	1.80	4.14	24	36	786
	$N_{375}K_{300}$	9.63**	15.8**	2.17	4.40	29	39	876

[1]Phosphorus was supplied at 90 kg P_2O_5/ha.
[2]Prices: garlic bolts and cloves = 1.30 and 1.00 Yuan/kg, K_2O = 2.33 Yuan/kg.
*, ** Difference significant at the 5% or 1% level, respectively.

Long-Term Phosphorus and Potassium Strategies in Irrigated Rice

By C. Witt, A. Dobermann, R. Buresh, S. Abdulrachman, H.C. Gines, R. Nagarajan, S. Ramanathan, P.S. Tan, and G.H. Wang

The site-specific nutrient management (SSNM) approach for rice provides sufficiently robust estimates of long-term fertilizer phosphorus (P) and potassium (K) requirements to avoid nutrient depletion. Additional information from long-term experiments may be required to fine-tune fertilizer P and K recommendations developed on-farm.

In this rice plot in the Philippines, severe K deficiency symptoms were observed where only N and P were applied.

Management of soil P and K is receiving greater attention in intensive, irrigated lowland rice systems of Asia because of concerns that fertilizer P and K rates are not optimally adjusted to long-term needs. Breeding offers limited opportunities to change the plant nutrient requirements or uptake efficiencies so that long-term management strategies must focus on overcoming immediate nutrient deficiencies and maintaining adequate nutrient balances in the topsoil layer. Current fertilizer P and K strategies in Asia are still mostly based on soil tests that have shown little correlation with the effective nutrient supply to the irrigated rice crop (Dobermann et al., 2003).

SSNM allows effective management of indigenous P and K supplies by estimating fertilizer requirements based on yield level, yield response to fertilizer P and K application, and a nutrient balance model (Fairhurst and Witt, 2002; Witt et al., 2002). In that approach, fertilizer P and K maintenance rates are commonly developed based on only 2 seasons of on-farm experiments, which may be insufficient to develop long-term strategies. In this paper, we evaluate SSNM strategies to prevent soil nutrient depletion using data from five long-term experiments established between 1968 and 1995 in China, India, Indonesia, the Philippines, and Vietnam.

Table 1. Maintenance fertilizer P_2O_5 rates (kg/ha) depending on yield in 0P plots and yield goal (adapted from Fairhurst and Witt, 2002).

Yield in 0-P plots, t/ha	Yield goal, t/ha 4	5	6	7	8
3	20	40	60	*	*
4	15	25	40	60	*
5	0	20	30	40	60
6	0	0	25	35	45
7	0	0	0	30	40
8	0	0	0	0	35

*A lower yield goal is recommended when the required yield increase exceeds 3 t/ha.

In the SSNM approach, fertilizer P and K rates are based on the yield difference between treatments with full fertilizer use of N, P, and K (NPK) and omission plots that receive all nutrients except for the omitted (0P, 0K). Recommended fertilizer rates are provided in simple charts (see example in **Table 1**). The NPK, 0P, and 0K treatments were also included in five long-term experiments with two rice crops per year, and the accumulated yield difference between NPK and omission plots for a period of up to 15 seasons are plotted in **Figure 1**. There were substantial differences in short- and long-term yield responses to fertilizer P and K application among sites. Yields were not affected by K application in India or P application in China in the first 2 seasons, and initial yield responses to fertilizer application were generally small except for Vietnam (P) and China (K). However, yield responses developed within a few seasons at all sites except for K application at Omon in the Mekong River Delta of Vietnam, where annual flooding supplies a large K load through sedimentation. Yield responses developed linearly except for China, where yield responses to P but not K application developed exponentially within 8 seasons or 4 years. Long-term fertilizer requirements would generally be underestimated, if fertilizer requirements were based only on short-term yield responses without considering nutrient removal with grain and straw and the overall input-output balance.

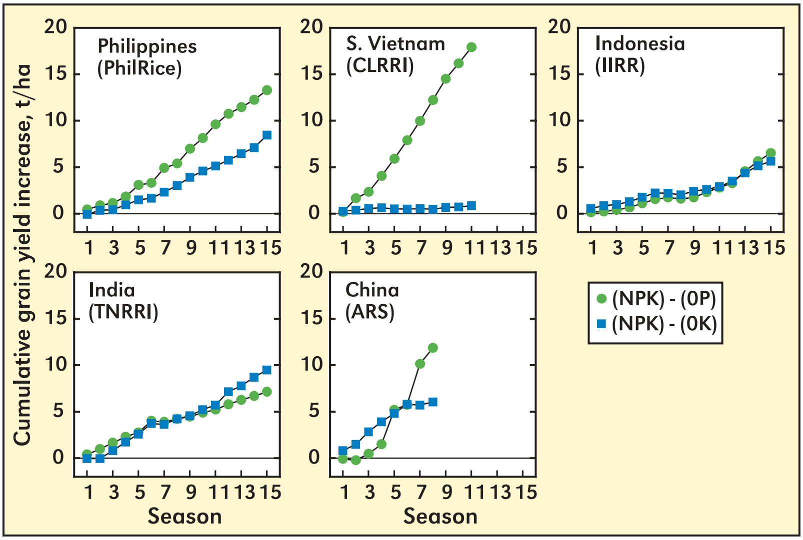

Figure 1. Cumulative grain yield increase in fully fertilized plots (NPK) over plots without fertilizer P (0P) and K (0K) application in long-term experiments at five sites in Asia, 1995-2002. PhilRice = Philippine Rice Research Institute, Muñoz, Philippines; CLRRI = Cuu Long Rice Research Institute, Omon, Vietnam; IIRR = Indonesian Institute for Rice Research, Sukamandi, Indonesia; TNRRI = Tamil Nadu Rice Research Institute (TNRRI), Tamil Nadu, India; ARS = Agricultural Research Station, Zhejiang, China.

In the absence of a yield response to fertilizer P and K application, SSNM recommends fertilizer P and K maintenance rates that are calculated based on a nutrient input-output model (Witt and Dobermann, 2004). Higher maintenance rates are suggested for higher yield levels because of a greater nutrient removal with grain and straw after harvest (see example in **Table 1**). Since initial yield responses appear to be generally small based on the presented data from long-term experiments, fertilizer requirements with SSNM may, to a larger extent, follow maintenance strategies. At issue is whether SSNM recommendations would need to be adjusted, if yield responses to fertilizer P and K application were evaluated for longer periods. **Table 2** shows fertilizer requirements calculated with SSNM based on data from 2 and 8 cropping seasons in the long-term experiments. Note that the actual fertilizer P and K rates were several times higher than the recommended rates with SSNM. High fertilizer P and K rates in long-term experiments are usually chosen to ensure that these nutrients are not limiting.

Considering 2 seasons of data, recommended fertilizer rates ranged from 21 to 32 kg P_2O_5/ha and from 20 to 48 kg K_2O/ha. Suggested rates were highest where both yield and yield responses to fertilizer application were high (Philippines, India, China). Fertilizer rates changed at some, but not all, sites when 8 instead of 2 seasons of data were considered in the calculation of fertilizer rates. Fertilizer rates needed little adjustment at sites where yield responses developed steadily and yields in NPK treatments remained more or less constant (e.g., Philippines). Adjustments in fertilizer rates were needed where yield levels in the first

Table 2. Average fertilizer rates and fertilizer requirements with SSNM (Fairhurst and Witt, 2002) based on the average yield increase (response) in N, P, and K fertilized plots (NPK) over plots without fertilizer P (0P) and K (0K) application during 2 and 8 cropping seasons in five long-term experiments in Asia.

Parameter	Unit	Philippines (PhilRice)	Vietnam (CLRRI)	Indonesia (IIRR)	India (TNRRI)	China (ARS)
		Fertilizer rates				
Starting year		1968	1995	1995	1995	1997
Fertilizer P_2O_5	kg/ha	60	57	57	57	57
Fertilizer K_2O	kg/ha	60	90	120	120	120
		Short-term fertilizer requirements				
Number of seasons		2	2	2	2	2
Grain yield (NPK)	t/ha	6.3	5.0	5.2	7.0	6.0
Yield response to P	t/ha	0.5	0.8	0.1	0.5	0.0
Yield response to K	t/ha	0.2	0.2	0.4	0.0	0.7
Fertilizer P_2O_5	kg/ha	28	23	21	32	24
Fertilizer K_2O	kg/ha	40	20	28	48	44
		Long-term fertilizer requirements				
Number of seasons		8	8	8	8	8
Grain yield (NPK)	t/ha	6.0	4.7	6.0	6.3	5.6
Yield response to P	t/ha	0.7	1.5	0.2	0.5	1.5
Yield response to K	t/ha	0.4	0.1	0.3	0.5	0.8
Fertilizer P_2O_5	kg/ha	27	30	25	28	29
Fertilizer K_2O	kg/ha	38	13	37	45	38

year were not representative for a longer time period, like in Indonesia, where yields increased with time. Adjustments were also needed where average yield responses to fertilizer application were either lacking or very strong over the 4-year period. A lacking yield response over a long period indicates a strong soil nutrient supplying power, while a strong yield response developed within a few seasons is a sign of a low soil buffering capacity to nutrient depletion. For example, 4 years of data from Omon revealed greater P, but lower K requirements compared to the rates calculated after one year. Despite these adjustments, the initial estimates of fertilizer requirements showed a good congruence with the fertilizer rates that were based on several seasons of data (**Figure 2**).

We therefore conclude that the SSNM approach would not have to be modified and that 2 seasons of data provide a first, sufficiently robust estimate of fertilizer P and K requirements. However, omission plots embedded in farmers' fields should be continued for several seasons at the same location, if data from long-term experiments are not available to identify the response pattern that develops over time and fine-tune SSNM recommendations.

In the last 4 years, the SSNM approach was disseminated with the involvement of more than 1,000 farmers in extension-led demonstration trials in Asia. The SSNM strategies were also incorporated into national initiatives in

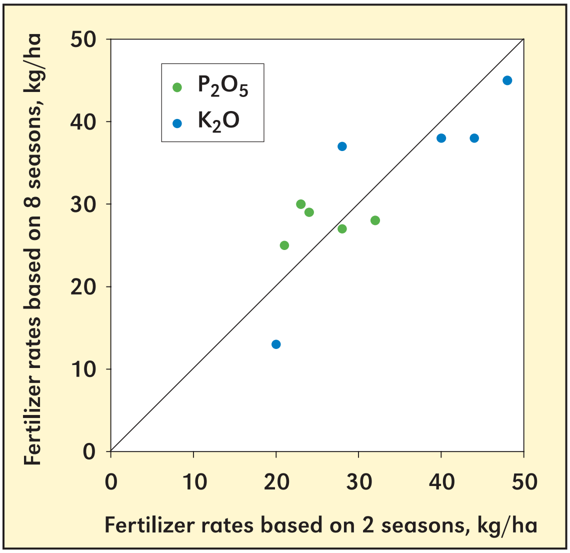

Figure 2. Fertilizer P_2O_5 and K_2O requirements with SSNM (Fairhurst and Witt, 2002) based on 2 and 8 seasons of data in long-term experiments at five sites in Asia, 1968-2002.

Bangladesh, India, Indonesia, Myanmar, and Vietnam. BC

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References

Dobermann, A., C. Witt, S. Abdulrachman, H.C. Gines, R. Nagarajan, T.T. Son, P.S. Tan, G.H. Wang, N.V. Chien, V.T.K. Thoa, C.V. Phung, P. Stalin, P. Muthukrishnan, V. Ravi, M. Babu, G.C. Simbahan, M.A. Adviento, V. Bartolome. 2003. Agron.J. 95:924-935.

Fairhurst, T. and C. Witt. (ed.) 2002. Rice: A practical guide to nutrient management. Singapore and Makati City: Potash & Phosphate Institute, Potash & Phosphate Institute of Canada (PPI/PPIC) and International Rice Research Institute (IRRI). p 1-89.

Witt, C., R.J. Buresh, V. Balasubramanian, D. Dawe, A. Dobermann. 2002. Better Crops Int. 16-2:10-17.

Witt C. and A. Dobermann. 2004. *In* Dobermann, A., C. Witt, D. Dawe, editors. Increasing productivity of intensive rice systems through site-specific nutrient management. Enfield, NH (USA) and Los Baños (Philippines): Science Publishers, Inc., and International Rice Research Institute (IRRI). p. 1-420.

Garlic... ***continued from page 31***

The highest shoot and clove yields were obtained with 300-90-300 kg/ha at Shuikou. The two sites at Xin'an had much higher yield potential and achieved much higher relative yields under all treatments. Both sites at Xin'an suggest a potential for even higher yields given the good performance of the highest N/highest K combination, which produced very large yields and profits.

The economics of garlic production were greatly improved with addition of 150 kg K_2O/ha, at both N rates. However, the data clearly show that 300 kg K_2O/ha applied with N at rates of 300 to 375 kg/ha, regardless of site, provide the best return to farmers.

The effects of widespread adoption of balanced fertilization in garlic production systems in Southeast China could have immense economic impact. **Results point to consistently large and profitable responses to rational NPK rates and no doubt enhance this production system in the eyes of farmers searching for viable cash cropping options.** BC

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Potassium Deficiency Symptoms in Vegetable Crops

By K.N. Tiwari and Gavin Sulewski

In recent years, the area under vegetables has increased in India, but there remains a large gap between potential yields and actual yields harvested by farmers. The appearance of potassium (K) deficiency symptoms in vegetable crops of India is becoming a common field problem. This article serves as a diagnostic tool for K management in vegetable crops.

India is endowed with favorable tropical, subtropical, and temperate climates, making it conducive for producing high quality, high value vegetables year round in various parts of the country. At present, 90 million tonnes (M t) of vegetables are produced from about 6 M hectares (ha)—less than 2% of the cropped land **(Table 1)**. For most vegetable crops, yields realized are less than 50% of the potential. By the year 2010, India will need to produce 160 M t of vegetables. Using an estimated land area of less than 8 M ha, this equates to a required increase in productivity of over 30%. This task calls for better crop husbandry, including the use of optimum rates of nitrogen (N), phosphorus (P), K, and other yield-limiting plant nutrients.

While the importance of balanced fertilizer use is widely recognized, its actual practice over much of the agricultural area in India continues to be neglected. Although India is the third largest user of fertilizers with the current annual consumption at around 18 M t, K fertilizers constitute only 9% of this; hence the necessity of emphasizing the role and importance of K in crop production. **Table 2** provides the basis for discussing the varied nutrient demands of vegetable crops. Considering an average 38 t/ha crop, vegetable production removes 148, 57, and 209 kg N, P_2O_5, and K_2O, respectively. Nutrient removal for the range of crops listed varies between 60 and 370 kg N/ha, 25 and 100 kg P_2O_5/ha, and 80 and 350 kg K_2O/ha. On average, plant uptake of K is 1.4 times more than N uptake.

Unbalanced fertilizer use (in this case application of only N or NP, but no K) leads to disproportional increase in K removal and reliance on the soil's K reserves. Without change in practice, each subsequent harvest exposes farm fields to the risks of low K supply. Out of the 361 districts surveyed several years ago for soil K fertility status, 47 districts were categorized as low (<120 kg K/ha), 192 were medium, and 22 districts were high (>280 kg K/ha). Such categories are still used for evaluating soil K status in the close

Table 1. Area, production, productivity, and potential yields of vegetable crops in India (2000).

Crop	Area, 000 ha	Production, 000 t	Productivity, t/ha Actual	Productivity, t/ha Potential
Potato	1,341	25,000	19	40
Brinjal	500	8,117	16	60
Onion	493	4,900	10	35
Tomato	457	7,427	16	50
Okra	349	3,419	10	20
Peas	273	2,712	10	20
Cabbage	258	5,909	23	70
Cauliflower	248	4,718	19	50
Others	2,074	28,629	14	40
Total	**5,993**	**90,831**	**15**	**43**

to 500 soil test laboratories operating in India. Since that survey, research data show that soils which initially tested high in K have become K-deficient due to heavy nutrient removal by harvested crop products and inadequate K application (Tiwari, 2001). Continued scant application of K fertilizers in the last two decades has left the number of districts in the low category virtually unchanged, whereas numbers in the high category have fallen considerably.

Table 2. Nutrient removal by selected vegetable crops grown in India.

Crop	Yield, t/ha	Nutrient removal, kg/ha N	P_2O_5	K_2O
Asparagus	5	120	60	150
Potato	40	175	80	310
Brinjal	60	175	40	300
Onion	35	120	50	160
Tomato	50	140	65	190
Okra	20	60	25	90
Peas (dry grain)	2	125	35	80
Cabbage	70	370	85	480
Cauliflower	50	250	100	350
Carrot	30	125	55	200
Celery	30	200	80	300
Cucumber	40	70	50	120
Green Beans	15	130	40	160
Radish	20	120	60	120
Pumpkin	50	90	70	160
Spinach	25	120	45	200
Leek	35	120	45	280
Lettuce	30	90	35	160
Table beet	30	150	50	220
Cassava	40	150	70	350
Sweet Potato	40	190	75	340
Beans (dry grain)	2	155	50	120
Mean	**38**	**148**	**57**	**209**
Nutrient Ratio		**100**	**39**	**141**

Potassium Deficiency Symptoms

It is importance to remember that long before symptoms of K deficiency become visible, severe losses in both crop yield and crop quality occur. **Figures 1 and 2** show how applied K can improve both yield and quality of vegetable crops. Application of 150 kg K_2O/ha gave an additional 5.9 and 6.2 t/ha of tomato and cauliflower, respectively (Rao, 1994). The increase in yield of carrot was 3.3 t/ha with 50 kg K_2O/ha.

The maximum increase in mean fruit weight was 27% with 100 kg K_2O/ha in cauliflower, 65% with 150 kg K_2O in tomato, and mean root weight increased by 29% with 50 kg K_2O in carrot.

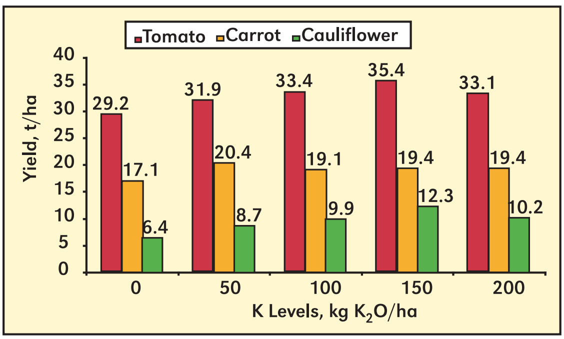

Figure 1. Effect of K application on yield of vegetables.

Because K is highly mobile within the plant, deficiency symptoms are first observed on older leaves. The physiological sequence for developing K deficiency symptoms is almost the same with all plants, although particular species, cultivars, or clones may exhibit somewhat different characteristic symptoms.

The first sign of K deficiency is a reduction in growth rate. Plants become stunted and usually leaf color becomes dark green. At a more advanced stage, specific deficiency symptoms appear. These include:

a. Decreased drought resistance.
b. Appearance of white, yellow, or orange chlorotic spots or stripes on older leaves, usually starting from the leaf tips and margins. In some species, irregularly distributed chlorotic spots appear, but in all cases symptoms start from the leaf tip. The base of the leaf usually remains dark green.
c. Chlorotic areas become necrotic, the tissue dies, and leaves dry up.
d. The symptoms spread to younger leaves and finally, under severe conditions, the entire plant may die.

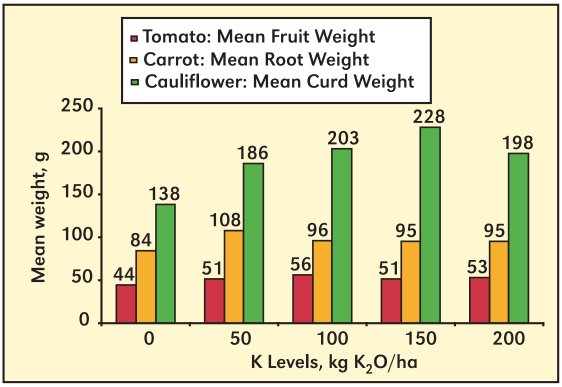

Figure 2. Effect of K application on quality of vegetables.

e. Roots of K-deficient plants are poorly developed and often affected by rot.

f. Disease incidence increases and crop quality is severely reduced, especially in the case of vegetables, fruit, tobacco, and fiber crops.

Apart from the above "typical" symptoms, other symptoms may occur as a result of imbalance of K with other nutrients, particularly N and calcium (Ca). Symptoms similar to K deficiency can also occur due to salt injury, fungus attack, and chemical spray damage. When diagnosing K deficiency in the field, these possible causes should be considered.

The following photos illustrate a few common K deficiency symptoms and effects in vegetable crops. For more photos and information, visit this website: **>www.ppi-ppic.org/ppiweb/gindia.nsf<.**

Amaranthus: Chlorosis and necrosis of leaf tips and withering of older leaves.

Okra: Chlorosis and necrosis of leaf tips and withering of older leaves.

Cowpea: Chlorosis and withering of margins of older leaves.

Conclusion

Symptoms of K deficiency are often seen in vegetable crops grown in India. They often go unattended because of lack of awareness by growers and extension workers. Negative soil K balances predominate—a situation that is not in the long-term interest of any farmer who plans to harvest progressively higher yields. New evidence shows that even traditionally recommended rates are insufficient to offset crop demand and effectively achieve high yields. **Including adequate K in a balanced fertilization program sustains profitable vegetable production.** BC

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References

Rao, Hari Prakash M. 1994. J. Potassium Res. 10(4): 402-406.

Tiwari, K.N. 2001. PPIC-India Programme.Tech. Bull. p. 48.

Dr. He and Dr. Li Selected to Join PPI/PPIC China Program Staff

Dr. He Ping and Dr. Li Shutian have joined the staff of the PPI/PPIC China Program and will be located in the Beijing office.

"We are pleased to welcome these two outstanding young scientists as they become involved with PPI/PPIC agronomic programs," said Dr. David W. Dibb, President of PPI. "Both will work closely with Dr. Jin Ji-yun, Director of our China Program."

Dr. He

Dr. He will serve as Deputy Director responsible for research and education programs in the Northcentral region of China, including Hebei, Henan, Shanxi, and Shandong provinces, plus Beijing and Tianjin. She was born in Yushu County of Jilin Province, an important area for crop production. Studying soil science and plant nutrition at Jilin Agricultural University, she earned a B.Sc. degree in 1992 and M.Sc. in 1995.

On completing her Ph.D. at the Graduate School of the Chinese Academy of Agricultural Sciences (CAAS) in 1998, she became an assistant professor in the Soil and Fertilizer Institute (SFI). In 2001, Dr. He was chosen by the Chinese Ministry of Science and Technology and the Science and Technology Agency of Japan to work on high yield maize (corn) research at Hokkaido University as a post-doctoral fellow. In 2003, she returned to SFI/CAAS to continue research on corn production and balanced fertilization. With emphasis on high yield, high quality, and high efficiency corn research, Dr. He is fully conversant with fieldwork and experiments. Her work on carbon and nitrogen interaction during grain formation (with Dr. M. Osaki in Japan) resulted in a published paper and talks at various symposia. Dr. He is active in professional societies, has published more than 30 papers, and has received wide recognition for her work.

Dr. Li

Dr. Li, the new Deputy Director for the Northwest region of China, will have responsibility for agronomic research and education efforts in these provinces: Xinjiang, Qinghai, Gansu, Ningxia, Shaanxi, and Neimeng (Inner Mongolia). A native of Hebei Province, Dr. Li grew up in a village and is familiar with agricultural production. He received a B.Sc. degree in 1988 at the Agricultural University of Hebei, completed his M.Sc. in 1991 and Ph.D. in 1999 at the Graduate School of CAAS.

In 1991, Dr. Li became a Research Scientist with SFI/CAAS. He participated in a research program on balanced fertilization techniques in different crops in Huang-huai-hai region from 1991 to 1995. From 1996 to 2002, he was part of a program on soil sulfur status and the effect of sulfur fertilizer on main crops in several provinces of China. Dr. Li also evaluated granular elemental sulfur effects on deficient soils and studied sulfur supply potential and availability in upland and paddy soils. In 2001/2002, he worked in a post-doctoral program in soil science at the University of Manitoba, with Dr. Don Flaten. Dr. Li's work has an awareness of practicing balanced fertilization and rational use of inputs.He has actively participated in many national and international symposia and workshops. Dr. Li has published more than 20 research papers in national and international journals. BC

Public Policy...and Fertilizers

Generally speaking, a good part of my ethnic background is what many refer to as 'Pennsylvania Dutch', early Germanic settlers in America who eschew worldly lifestyles. I'm fond of one of their sayings, which translates into English as:

"Too soon old, too late smart."

You ask: What does that have to do with public policy and fertilizers? Concerning the efforts of the crop nutrient industry and its partners in research and education around the world to convey the value and benefits of crop nutrients ... fertilizers ... to the public, we have been "too late smart." Possibly it's only me.

Recently, I have come to the realization that rather than leading an argument with 'Fertilizers are good because they...improve food security, farmer income, etc.', I might have been more effective by reversing the elements of the argument, by first addressing the issue of concern to the public. After all, isn't the public most interested in having a sufficient, diverse, and wholesome food supply offered at reasonable prices. And isn't society more keenly interested in having a healthy rural economy so farmers have the wherewithal to provide the food we need as well as to secure the vast landscape they have stewardship over, so it can be enjoyed by countless generations to come...than talking about fertilizers? And after all, aren't fertilizers a means to a good and noble end...not the end itself?

My point is: We have battled on and about fertilizers...and not very convincingly...to the public. There is another way, a smarter way. I may claim "too soon old, too late smart", but I trust there are many younger, more vital, and smarter 'fertilizer people' among the research, education, and industrial communities who understand. First, address the issues of public concern, of public policy...then explain fertilizer's role and its effectiveness. This piece is purposely titled: *Public Policy...and Fertilizers*. In that order, please.

Work smart. Be effective.

Dr. Mark D. Stauffer,
Senior Vice President,
International Programs, PPI
and President, PPIC

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