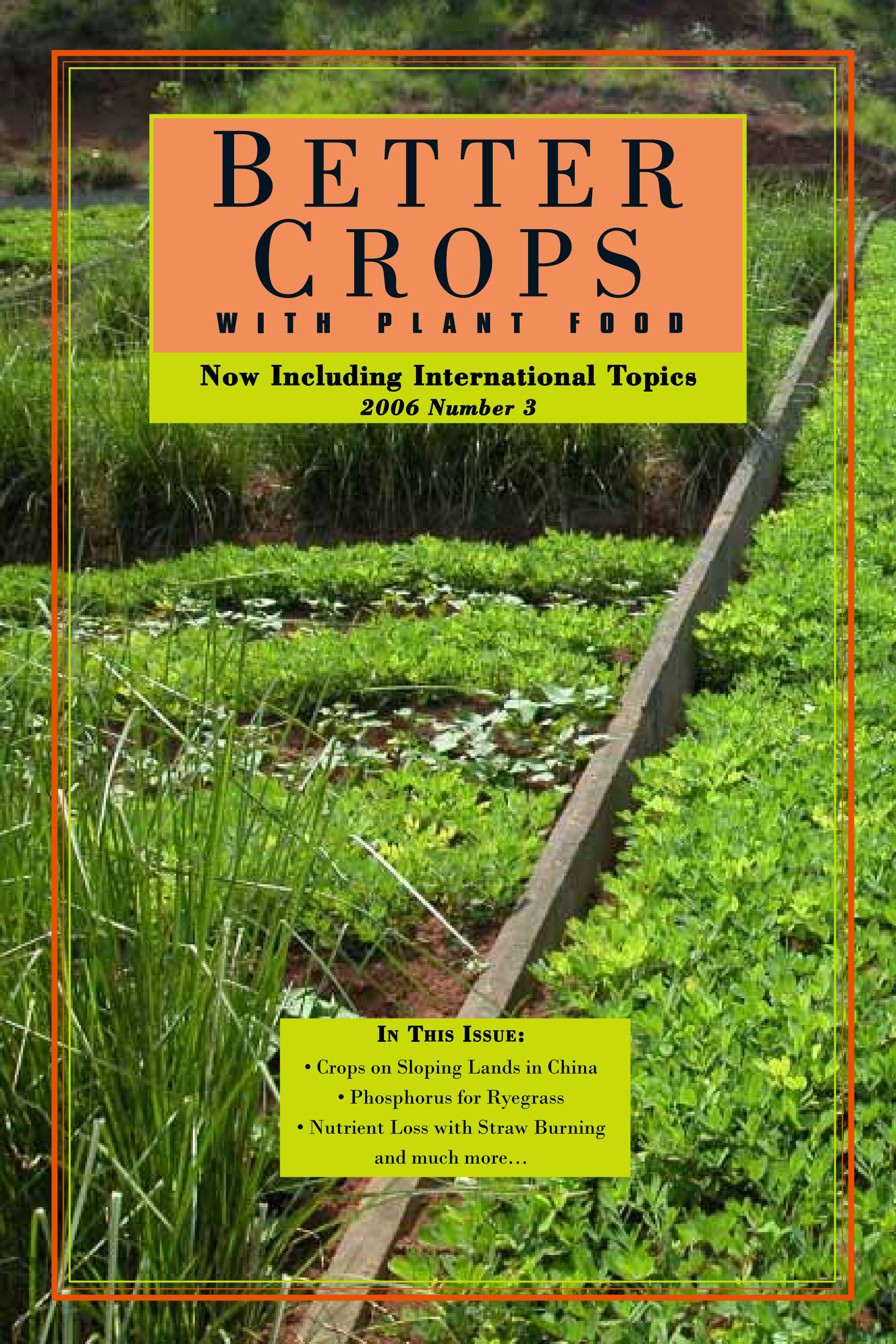

BETTER CROPS

WITH PLANT FOOD

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2006 Number 3

IN THIS ISSUE:

- Crops on Sloping Lands in China
- Phosphorus for Ryegrass
- Nutrient Loss with Straw Burning

and much more…

BETTER CROPS
WITH PLANT FOOD

Vol. XC (90) 2006, No. 3

Our cover: Bio-terracing of crops on sloping lands in southwest China.
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International Section

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Winners of Robert E. Wagner Award for 2006

Two outstanding agronomic scientists have been selected to receive the 2005-2006 Robert E. Wagner Award by PPI. The award encourages worldwide candidate nominations and has two categories… Senior Scientist and Young Scientist, under the age of 45. The recipient in each category receives $5,000 along with the award plaque.

Dr. David E. Kissel, Professor and Director, Agricultural and Environmental Services Laboratories, University of Georgia, receives the Senior Scientist Award. **Dr. Nathan A. Slaton,** Associate Professor, Director of Soil Testing, University of Arkansas Agricultural Experiment Station, receives the Young Scientist Award.


Dr. D.E. Kissel


Dr. N.A. Slaton

The award recognizes distinguished contributions to advanced crop yields through maximum yield research (MYR) and maximum economic yield (MEY) management. It honors Dr. Robert E. Wagner, President (retired) of PPI, for his many achievements and in recognition of his development of the MEY concept…for profitable, efficient agriculture.

Dr. Kissel is a highly respected scientist and administrator whose career has been devoted to enhancing and understanding the fate and dynamics of fertilizer nutrient applications. He has worked diligently to transfer his research results into management practices that will increase fertilizer efficiency, crop yields, and producer profitability. Dr. Kissel's research on plant nitrogen (N) nutrition has significantly contributed to improved efficiencies of urea fertilizers. His recent efforts related to variability in southeast U.S. soils have had considerable impact in that he has integrated the effects of soil physical and chemical properties into management systems that increase productivity and protect the environment. Dr. Kissel earned his B.S. degree at Purdue University in 1965 and his M.S. in 1967 and Ph.D. in 1969 at the University of Kentucky in soil chemistry. He studied yield response by forages and crops at the Blackland Research Center in central Texas and identified key management practices that improve N use efficiency. Dr. Kissel was at Kansas State University from 1978 to 1988 where he continued research on N-phosphorus (P) fertilizer placement and expanded that work to determine the effect of band spacing, P source, and other factors on efficient fertilizer use and wheat yield.

Dr. Slaton's current research program focus is to update P and potassium (K) recommendations in Arkansas for rice, soybeans, and winter wheat by conducting correlation-calibration studies. His program is also developing guidelines for use of poultry litter as a nutrient source for crops, examining polymer coated-urea as a potential preplant incorporated N source for flood irrigated rice, relationships among rice diseases/nutrient management/production practices, and sustainable K fertilization strategies for rotations involving rice and soybeans. Many of his earlier research findings have been incorporated into management recommendations and adopted by growers. A native of Indiana, Dr. Slaton earned his B.S. degree at Murray State University (Kentucky) in 1986, then moved to the University of Arkansas where he completed his M.S. in 1989 and Ph.D. in soil fertility in 1998. From 1995 to 2001, he was Extension Agronomist–Rice, with University of Arkansas Cooperative Extension. BC

For more about the Wagner Award and 2006 recipients, visit the website at: ***>www.ppi-ppic.org/pr<.***

J. Fielding Reed PPI Fellowships Awarded To Four Graduate Students

Four outstanding graduate students have been announced as the 2006 winners of the J. Fielding Reed PPI Fellowhips awarded by the Potash & Phosphate Institute (PPI). Grants of $2,500 each are presented to the individuals. All are candidates for either the Master of Science (M.S.) or the Doctor of Philosophy (Ph.D.) degree in soil fertility and related fields. The winners for 2006 are:

- **Dennis W. Hancock**, University of Kentucky
- **Neil S. Mattson**, University of California-Davis
- **Emily G. Sneller**, University of Wisconsin-Madison
- **Mark W. Szczerba**, University of Toronto

"It is a privilege of our organization each year to recognize these excellent young individuals who represent such dedication and strong qualification in sciences relevant to plant nutrition. Since these awards began in 1980, nearly 160 graduate students have received Fellowships from the Institute," said Dr. Terry L. Roberts, President of PPI.

Funding for the Fellowships is provided through support of potash and phosphate producers who are member companies of PPI. Scholastic record, leadership, and excellence in original research are among the important criteria evaluated for the Fellowships. Following is a brief summary of information for each of the 2006 recipients.


Dennis W. Hancock

Dennis W. Hancock is completing his Ph.D. in Crop Science at the University of Kentucky, Lexington. His dissertation title is "Spectral Reflectance of Canopies of Rainfed and Subsurface Irrigated Alfalfa." A native of Dawson Springs, he attended Berea College and earned his B.S. degree there in 1997. After receiving his M.S. at the University of Kentucky, Mr. Hancock worked as Extension Agent for Agriculture and Natural Resources in Grant County (Kentucky) from 2000 to 2002. Since 2002, he has served as Research Specialist and Extension Associate for Precision Agriculture statewide, coordinating the Multispectral and Subsurface Drip Irrigation Research Project. He has also maintained the university's website, "Precision Agriculture in Kentucky." One aspect of his work provides the foundation for development of a novel method for fine-tuning potassium fertilization of alfalfa. For the future, he hopes to help farmers improve yields and input use efficiency, decrease environmental impact, and increase profitability.


Neil S. Mattson

Neil S. Mattson is a candidate for a Ph.D. degree in Plant Biology at the University of California-Davis. His dissertation title is "Macronutrient Absorption during Growth Cycles of *Rosa* Hybrida: Role of Carbohydrate, Nitrogen, Phosphorus, and Potassium Storage and Reallocation on Plant Nutrient Absorption." Originally from Minnesota, Mr. Mattson received his B.A. degree from the University of Minnesota-Morris in 2000 and his M.S. in 2002 at the University of Minnesota-St. Paul. The overall objectives of his dissertation are to develop methods to provide optimal levels of nitrogen, phosphorus, and potassium to rose plants in a manner that will reduce leaching of the nutrients while still maximizing plant yields. In addition to his project on mathematical modeling of nutrient uptake in greenhouse crops, Mr. Mattson is also working with his major professor in software development of a greenhouse production timing tool for cut-flower rose production. His career goal is a university position that combines research with outreach efforts, with a focus on water and nutrient management in agronomic or horticultural crops.


Emily G. Sneller

Emily G. Sneller is pursuing her M.S. degree in Soil Science at the University of Wisconsin. Her thesis title is "Manure Source and Rate Effects on Soil Test Levels and Corn Growth in Relation to Fertilizer." Originally from Michigan, Ms. Sneller grew up on a dairy farm and received her B.S. in 2005 from Michigan State University. Her current research project involves three main focus aspects. First is a field study to determine manure phosphorus availability to corn compared to fertilizer. Then, the same locations will be used to determine second year availability of each source. Third, an in-laboratory incubation study will be done to mirror the field study. Results of the various components will help fine tune phosphorus recommendations related to manure application. For the future, Ms. Sneller hopes to work with farmers in developing efficient and sustainable management plans while maintaining the effectiveness and economical aspects required in modern agriculture.


Mark W. Szczerba

Mark W. Szczerba is working toward a Ph.D. in Plant Physiology in the Botany Department at the University of Toronto. His thesis title is "Physiology of Potassium Nutrition in Cereals: Fluxes, Compartmentation, and Ionic Interactions." Mr. Szczerba completed his B.S. degree at the University of Western Ontario in 2002. His current research focus is on potassium (K^+) nutrition in barley and rice seedlings, seeking to better understand fundamental aspects concerning K^+ transport. His findings related to low-affinity transport of K^+ in cereals have already provided new insight and reworking of methodology for flux measurement in plants. He is also exmamining sodium (Na^+) stress in cereals, in particular, how Na^+ toxicity affects K^+ uptake and compartmentation. As for future career goals, Mr. Szczerba would like to use his skills and knowledge in ion transport to better understand how to engineer plants that one day could be used to decontaminate soils laden with heavy metals or organic toxicants.

The Fellowships are named in honor of Dr. J. Fielding Reed, who served as President of the Institute from 1964 to 1975. Dr. Reed was well-known for inspiring advanced study and for encouragement of students and teachers. The 2006 Fellowship winners were selected by a committee of PPI scientific staff. BC

How to Apply for PPI Fellowship

Graduate students attending a U.S. or Canadian degree-granting institution are eligible to apply for the J. Fielding Reed PPI Fellowships. The award is made directly to the student and no specific duties are required. Deadline for the next round of applications to be received is January 16, 2007. Announcement of those awards would be in the spring of 2007. Applicants are asked to include transcripts of all college courses and letters of support from three individuals (one of whom should be the major professor). Application forms are available by contacting: Phyllis Pates, PPI, 772-22nd Avenue South, Brookings, SD 57006; phone (605) 692-6280; e-mail: ppates@ppi-far.org. BC

Phosphorus Fertilization of Annual Ryegrass

By T.J. Butler, J.P. Muir, T. Provin, and W.M. Stewart

Annual ryegrass is an important forage crop in the southern U.S. It has good yield potential and excellent nutritive value. This central Texas study has demonstrated the importance of both nitrogen (N) and phosphorus (P) fertilization in ryegrass production. The optimal rate of P fertilization was either 40 or 60 lb/A, and optimal N rate was 200 or 300 lb/A, both depending on seasonal rainfall distribution. Interestingly, there was relative agreement between removal of P in forage and optimal P fertilizer rate. These results demonstrate, and further confirm, the importance of balancing nutrient inputs in forage production to optimize yield, quality, and grower profit.

Annual ryegrass provides highly nutritious herbage in the southeastern U.S. during a critical time of the year when both forage availability and quality are limiting. Depending on latitude, ryegrass is planted or allowed to self-reseed where it is naturalized from September to October and then grazed during the winter and spring. Ryegrass responds well to N fertilizer. However, that response may be limited by insufficient P. This is particularly true on soils that are low in P, such as those that occur in much of northcentral Texas and south-central Oklahoma.

Our objectives in this study were to: 1) evaluate annual ryegrass yield response to annual applications of various rates of N and P fertilizer, paying particular attention to interaction between nutrients and application rates and, 2) evaluate the accuracy of two soil test-P methods: Mehlich-3 and ammonium acetate (NH_4OAc)-EDTA (formerly called the Texas A&M method).

Balanced fertilization of annual ryegrass optimizes yield, quality, and profitability.

This study was initiated in September 2001 on a Windthorst sandy loam soil (Udic Paleustalf) in northcentral Texas near Stephenville. Initial soil tests indicated these results: soil pH, 5.1; nitrate (NO_3)-N, 6 parts per million (ppm); P, 6 ppm (low, NH_4OAc-EDTA extractant); and potassium (K), 205 ppm (high). A split-plot randomized complete block design with four replications, six main treatments, and two sub-treatments was established. Main plots received annual applications of 0, 20, 40, 60, 80, and 100 lb P_2O_5/A/year. Phosphorus from triple superphosphate (0-46-0) was preplant-incorporated 6 to 8 in. deep. Subplots received annual split applications of 200 or 300 lb N/A/year. Nitrogen (34-0-0) applications were split-applied, with half applied at planting and the remainder in February. Ryegrass was planted at 30 lb seed/A each year to ensure adequate stands.

Plots were harvested four times on monthly intervals (February through May) during 2001-02, 2002-03, and 2003-04. Ryegrass yield for each harvest was determined for each treatment and samples were analyzed for N, P, neutral detergent fiber (NDF), and acid detergent fiber (ADF). Nitrogen concentration was multiplied by 6.25 and reported as crude protein (CP).

Soil samples (6 in. depth) were taken from each plot at the end of each growing season to determine treatment differences. Soils were analyzed for pH using a 1:2 ratio of soil to deionized water, NO_3-N by cadmium (Cd) reduction, and sodium (Na), magnesium (Mg), sulfur (S), K, calcium (Ca), and P based on two soil-extractant methods: acidified NH_4OAc-EDTA and Mehlich-3. After the 2002-03 growing season, 1.5 tons/A ECCE (effective calcium carbonate equivalent) dolomitic limestone was added to all plots to adjust the average soil pH from 4.9 to 5.8.

Total seasonal (September through June) rainfall differences were relatively small. Precipitation in the first growing season totaled 29.2 in., 30.5 in. for the second season, and 31.0 in. during the third season. Although total seasonal rainfall among the 3 years was similar, the difference in distribution among growing seasons was substantial (**Figure 1**). The second growing season (2002-03) had the best early and midseason moisture…45% of the season total fell by the end of January 2003 (i.e., midseason). During the first and last seasons (2001-02 and 2003-04) 36% and 25%, respectively, of the season totals fell by the end of January. Overall, seasonal rainfall distribution was superior for ryegrass production in the second season.

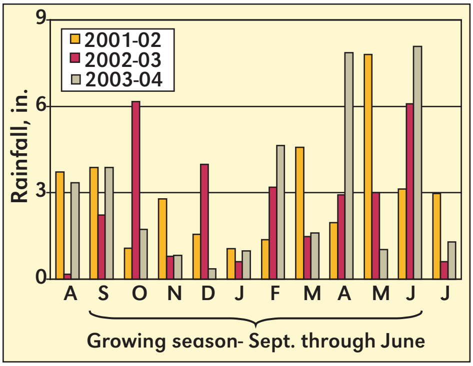

Figure 1. Monthly precipitation, August to July, during 3 years at Stephenville, Texas.

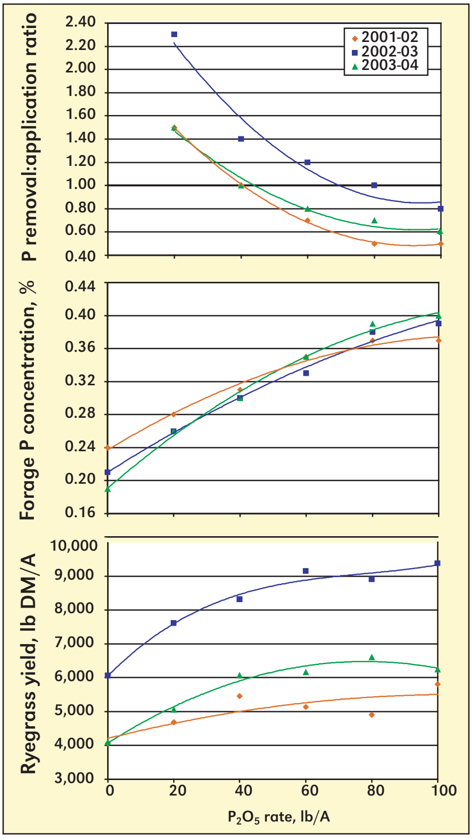

Figure 2. Response of TAM90 annual ryegrass dry matter forage yield, P concentration, and removal to application ratio to rates of P at Stephenville, Texas.

Ryegrass dry matter (DM) yields were greatest in the 2002-03 growing season, while the 2001-02 and 2003-04 seasons were similar (**Figure 2**). Increasing yearly N fertilizer rates from 200 to 300 lb significantly increased ryegrass yields only in the 2002-2003 season (**Table 1**) when yield potential was higher due to superior rainfall distribution.

In 2001-02, ryegrass yields increased 34% from the zero P control to the optimal rate of 40 lb P_2O_5/A (**Figure 2**). Yield

Table 1. Nitrogen rate effect on annual ryegrass yield and crude protein content.

N rate, lb/A	Parameter		
	2001-02	2002-03	2004-05
	- - - - - Dry matter yield, lb/A- - - - -		
200	4,842	7,877	5,632
300	5,176	8,593	5,780
LSD, p=0.05	NS	536	NS
	- - - - - - Crude protein, % - - - - - -		
200	23.1	21.6	18.6
300	25.8	25.8	22.2
LSD, p=0.05	0.9	0.7	0.7

at the 40 lb P_2O_5/A rate did not differ from the 60, 80, or 100 lb P_2O_5/A rates. In 2002-03, ryegrass yields increased 26% from the addition of 20 lb P_2O_5/A, 37% with 40 lb P_2O_5/A, and 51% at optimal production with 60 lb P_2O_5/A. The 60 lb rate did not differ from the 80 or 100 lb P_2O_5/A rates. In 2003-04, ryegrass yields increased 23% from the application of 20 lb P_2O_5/A and 48% with the optimal rate of 40 lb P_2O_5/A, which did not differ from 60, 80, or 100 lb P_2O_5/A rates.

The 300 lb N/A/year treatment increased CP concentration over the 200 lb N treatment (**Table 1**). Forage N concentration in the 200 lb N/A plots was well over the critical N concentration (11.3% CP) required to produce over 90% of maximum yield (Robinson and Ellers, 1996). Therefore, it is assumed that N was not limiting at the lower rate.

Phosphorus fertilizer rate did not affect CP levels in the ryegrass. However, P fertilizer increased total CP yields up to the 40 lb P_2O_5/A/year treatment (data not shown). This total CP increase was a direct result of forage yield increase from P fertilizer and reached 60% over the control plots during the year with the best rainfall distribution (2002-03).

The addition of P fertilizer increased P concentration in the ryegrass throughout the study (**Figure 2**). The average concentrations were 0.21, 0.27, 0.30, 0.34, 0.38, and 0.39% P for the 0, 20, 40, 80, and 100 lb P_2O_5/A rates, respectively. Similar results have been reported for ryegrass grown in other soils (Hillard et al., 1992; Rechcigl, 1992; Robinson and Ellers, 1996). Phosphorus yields in the forage were greatest at the highest forage yield (2002-03). Apparent P fertilizer recovery efficiency was greatest at the lower P fertilizer rates (18 to 31% at the 20 lb P_2O_5/A vs. 12 to 22% at the 100 lb P_2O_5/A rate). It is important to note that apparent P fertilizer efficiency can be misleading and is commonly greatest at low levels of input in low testing soils. In this case, apparent efficiency should be distinguished from sustainable efficiency (Dibb et al., 2003). Annual ryegrass forage ADF and NDF did not differ among P or N treatments.

An interesting aspect of forage fertilization is the evaluation of nutrient uptake and removal compared to fertilizer application rate. Where forage crops are harvested and biomass removed from fields (e.g., hay and silage production) nutrient uptake is practically equal to nutrient removal. An instructive way to evaluate the relationship between nutrient removal and nutrient application with relatively immobile elements such as P and K is through the removal:application ratio. If the removal:application ratio is less than 1 then more of the nutrient in question is being applied than is being removed. Where this is the case with elements such as P and K, soil test levels should increase over time. On the other hand, where the ratio is greater than 1, more is being removed than applied and soil test levels should decline.

Figure 2 also shows the P removal: application ratios for each P application rate from each year of the study. It is worth noting that the optimal rates of P application for years 1 and 3 (40 lb P_2O_5/A) coincided with a removal:application ratio of 1 (i.e., the point where removal equals addition). The removal:application ratio at the optimal rate of P application in year 2 (60 lb P_2O_5/A) was 1.2.

Stepwise multiple regression analysis was used to evaluate the impact of extractable soil P from both the Mehlich-3 and NH_4OAc-EDTA methods on annual ryegrass yield. Each annual plot yield was

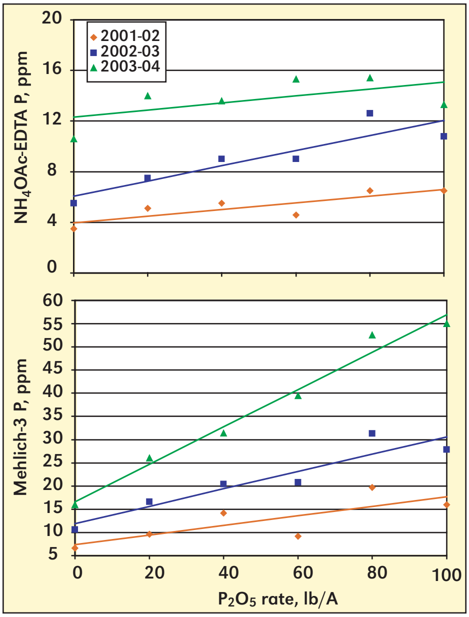

Figure 3. Soil P levels from two methods of extraction after the 2002, 2003, and 2004 growing seasons at Stephenville, Texas.

normalized against relative yield (%RY) potential. Soil test P data obtained from the NH_4OAc-EDTA method was not correlated to %RY. The multi-variant equation representing %RY, developed using the Mehlich-3 soil test P data, included P fertilizer rate (lb P_2O_5/A), soil pH, and Mehlich-3 P (ppm) soil test data. The equation is as follows:

$\%RY = 108.95 + 0.174 * P\ rate - 10.471 * pH + 0.175\ Mehlich\text{-}3\ P$

$r^2 = 0.484\ \ P < 0.001.$

There was a trend towards greater soil-P concentration over years for both methods evaluated (**Figure 3**). This was apparent even in plots where no fertilizer P was applied. Although soil pH certainly had an effect on soil-P availability following the application of lime in 2003-04, other factors were involved in the 2002-03 increase since pH levels tended to decrease that year compared to 2001-02. Perhaps organic P from native organic matter and forage materials incorporated prior to the initiation of this study contributed to the increase in extractable P.

Ryegrass response to P fertilizer rates was independent of the two N fertilizer rates used in this study. The optimal fertilizer rates for annual ryegrass production were 40 lb P_2O_5/A/year and 200 lb N/A/year in the 2001-02 and 2003-04 growing seasons. However, in the 2002-03 season, when rainfall distribution was superior to the other years, the optimal rates were 60 lb P_2O_5/A and 300 lb N/A. Where P fertilizer was applied, the average removal of P_2O_5 in ryegrass forage was 51 lb/A. Interestingly, there was relative agreement between removal of P in forage and optimal P fertilizer rate. These results confirm the importance of balancing nutrient inputs in forage production.

Dr. Butler, formerly with Texas A&M University (TAMU), is now Assistant Scientist with the Noble Foundation, located at Ardmore, Oklahoma; e-mail: tjbutler@noble.org. Dr. Muir is Associate Professor, TAMU, Stephenville. Dr. Provin is Associate Professor and Soil Chemist, TAMU, College Station. Dr. Stewart is PPI Southern and Central Great Plains Regional Director, located at San Antonio.

PPI/FAR Research Project 48-F.

References

Dibb, D.W., P.E. Fixen, and M.D. Stauffer. 2003. Fertilizer use efficiency: The North American experience. Better Crops with Plant Food. Vol. 87, No. 3, p. 3.

Hillard, J.B., V.A. Haby, and F.M. Hons. 1992. Annual ryegrass response to limestone and phosphorus on an ultisol. Commun. Soil Sci. Plant Anal. Vol. 23. p. 175-188.

Rechcigl, J.E. 1992. Response of ryegrass to limestone and phosphorus. J. Prod. Agric. 5: 602-607.

Robinson, D.L. and T.L. Ellers. 1996. Phosphorus and potassium influences on annual ryegrass production. Louisiana Agriculture. 2: 10-11.

Up in Smoke—
Nutrient Loss with Straw Burning

By John Heard, Curtis Cavers, and Greg Adrian

Burning spring wheat, oat, and flax straw resulted in 98 to 100% loss of nitrogen (N), 70 to 90% loss of sulfur (S), and 20 to 40% loss of phosphorus (P) and potassium (K).

In the province of Manitoba in western Canada there is considerable controversy regarding the value and costs of returning straw from crops to the soil. In much of Manitoba, ample growing season moisture produces high straw yields. This straw is sometimes burned in the fall when it cannot be marketed for fibre, or when it impairs tillage and seeding operations the next spring. The most obvious consequence of straw removal or burning is the loss of plant nutrients.

Past work on straw management in this region has estimated that straw burning produced total loss of N and S, with no loss of P and K. As a result, subsequent guidelines have considered this the standard nutrient loss from burning. In an attempt to clarify this estimate, a study was carried out to evaluate the fertility value of straw and the losses that occur during removal or burning.

Spring wheat, oat, and flax straw samples were collected in three regions of Manitoba with a portion retained for straw nutrient analysis and the remaining portion burned on a steel grate to allow retention and collection of the resulting ash. Ash weight from the burn was determined, and the resulting straw and ash samples were submitted for analysis of total carbon (C), N, P, K, and S.

Straw rows burning at night to control spread of fire.

Straw samples were between 4 to 6% moisture content and much of the straw mass was lost during burning. The amount of straw weight lost through burning varied greatly among sources, with flax burning more completely and only 4% of the mass remained as ash versus 8% for oats and 13% for wheat.

The nutrient concentration in straw and resulting ash is presented in **Table 1**. The amount of C in straw varied little within straw types. The amount of C remaining in the ash varied more as a result of the degree of combustion (where less combustion, more C remained). The N content of straw generally varied more than other nutrients. Variation in straw nutrient content is expected as it reflects the

Caution When Soil Sampling Burned Fields

Burning crop residue to improve equipment operation is a common practice on no-till fields in parts of the northern Great Plains. However, one must be careful when soil sampling fields where crop residue has been burned in the windrows. An agronomist working in northeast Saskatchewan reported that a composite soil sample from a burned field gave a false reading on soil test K. While the field composite reading was 223 parts per million (ppm) K, further sampling found that 25% of the field where the windrows were burned was 325 ppm, while the remaining 75% of the field was 114 ppm. So, be cautious of misleading results when sampling burned fields.

Table 1. Nutrient content (%) in harvested straw and ash from spring wheat, oats, and flax.

Nutrient	Material	Spring wheat	Oats	Flax
Carbon	Straw	41(1.02)[1]	42 (0.15)	46 (0.26)
	Ash	24 (15.4)	19 (9.8)	39 (12)
Nitrogen	Straw	0.97 (0.31)	0.64 (0.38)	0.86 (0.18)
	Ash	1.09 (0.67)	0.48 (0.23)	1.40 (0.47)
Phosphorus	Straw	0.14 (0.05)	0.08 (0.04)	0.07 (0.03)
	Ash	0.97 (0.5)	0.76 (0.26)	1.30 (0.90)
Potassium	Straw	1.44 (0.77)	2.34 (0.97)	0.24 (0.05)
	Ash	9.82 (6.76)	19.40 (10.5)	3.73 (1.24)
Sulfur	Straw	0.11 (0.05)	0.22 (0.28)	0.06 (0.006)
	Ash	0.30 (0.25)	1.28 (2.02)	0.20 (0.09)

[1] Value in brackets represents 1 standard deviation of the mean.

differing management and fertility regimes the crop is grown under. Nitrogen concentration of the ash is similar in magnitude to the concentration in straw. Unlike N, the P, K, and S tended to be concentrated 2 to10 times more in ash than in the original straw. This concentration of nutrients indicates increased retention in the ash left after the burning was carried out.

Nutrient loss through burning is illustrated in **Table 2**, where the amount of nutrients present in one ton of straw is compared before and after burning. Carbon and N loss due to burning was greater than 90% across all straw types and sources. On average, 98 to 100% of the N, 24% of the P, 35% of the K, and 75% of the S was lost through burning.

While the loss of N and S with burning agrees with previous assumptions, the primary question asked from these results was: Where did 24% of the P and 35% of the K go? It is likely that most of the loss was smoke or particulate matter that drifted away from the fire, since no attempt was made to collect or retain it. There is some possibility that this particulate matter may settle down over the field being burned – but this will depend on wind and other smoke dispersion factors. Other factors like high temperature volatilization of K may explain the loss, but are less likely.

Determining the economic impact of burning straw may be as difficult as when straw is baled. A complete job of burning converts the vast majority of all above-ground straw and chaff to ash, while baling removes only a portion of the straw, and usually no chaff. However, the usual objective is to burn only that excess straw that is dropped in the swath, leaving stubble intact between swaths. Such burning practices can also influence nutrient distribution in a field, especially when straw is burned in rows dropped behind a combine. The result is nutrients concentrated along this row position in the field. Soil sampling should avoid any cores from these ash rows. The variability in straw nutrient content observed in this study supports the argument that straw nutrient content is largely influenced by the grower's fertility management.

Mr. Heard, CCA, (e-mail:jheard@gov.mb.ca) is Provincial Soil Fertility Extension Specialist; Mr. Cavers, CCA, is Provincial Land Management Extension Specialist; Mr. Adrian is a Soil Survey Technician, all with Manitoba Agriculture, Food and Rural Initiatives in Carman, Manitoba.

Table 2. Nutrient content (lb) in one ton of harvested straw and ash from spring wheat, oats, and flax.

Nutrient	Material	Spring wheat	Oats	Flax
Carbon	Straw	826 (23)	832 (3.4)	910 (5.8)
	Ash	77 (100)	31 (22)	28 (12.3)
Nitrogen	Straw	22 (14.9)	10 (5.04)	28 (10.3)
	Ash	0.4 (0.22)	0.1 (0.07)	0.05 (0.03)
Phosphorus[2]	Straw	2.7 (1.02)	1.5 (0.77)	1.4 (0.74)
	Ash	2.4 (1.50)	1.3 (0.50)	0.9 (0.77)
Potassium[2]	Straw	29 (17)	47 (21)	4.7 (1.12)
	Ash	24 (16)	30 (17)	2.6 (1.03)
Sulfur	Straw	2.2 (1.06)	4.4 (6.11)	1.1 (0.13)
	Ash	0.7 (0.51)	2.2 (3.76)	0.14 (0.03)

[1] Value in brackets represents 1 standard deviation of the mean.

[2] Convert P and K values to P_2O_5 and K_2O equivalent by multiplying values by 2.29 and 1.2, respectively.

Forest Fertilization in Southern Pine Plantations

By T.R. Fox, H.L. Allen, T.J. Albaugh, R. Rubilar, and C.A. Carlson

Forest fertilization is a widespread silvicultural practice in the southeastern U.S. About 1.2 million acres of pine plantations were fertilized with phosphorus (P) or nitrogen (N) plus P in 2004. The average growth response of loblolly pine plantations following midrotation fertilization with N+P is approximately 50 ft^3/A/yr for 8 years. Internal rates of return in excess of 10% can be obtained after midrotation fertilization under current market conditions.

The southeastern U.S. produces more timber than any other region of the world from a forest base that now includes almost half of the world's forest plantations. There are currently 32 million acres of pine plantations in the southeastern states, predominantly comprised of loblolly pine (*Pinus taeda* L.) and to a lesser extent slash pine (*Pinus elliottii* Englemn.) The growth rate in the pine plantations in the region currently averages around 5 green tons/A/yr, which is substantially lower than in many forest plantations in other parts of the world. Theoretical models, empirical field trials, and operational experience show that these growth rates are well below what is possible. With investment in appropriate intensive plantation silvicultural systems, growth rates exceeding 10 tons/A/yr are biologically possible and financially attractive for a broad range of site types. Forest fertilization should be included in silvicultural regimes that are designed to enhance plantation growth in the region.

Ecophysiology and Tree Nutrition

It is now generally accepted that much of the variation in wood production in forest plantations is caused by variation in light interception. Light interception is principally a function of the amount of leaf area in a stand. Studies with loblolly pine and slash pine have shown that leaf area, and consequently wood production, are below optimum levels in most of the Southeast (**Figure 1**). Low nutrient availability is a principal factor causing subop-

Increased growth of pine trees with fertilization (left), compared to trees without fertilization (right), is illustrated in these Alabama plots.

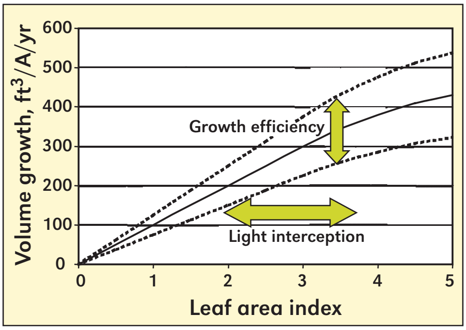

Figure 1. Relationship between annual volume growth and leaf area in southern pine plantations in the Southeastern U.S.

timal leaf area in many areas.

From a resource availability perspective, water availability…whether too little or too much…has historically been considered the principal resource limiting pine productivity in the South. While this is true for recently planted pine seedlings on many sites and for specific soil types (e.g. very wet or very dry soils) throughout the rotation (planting to tree harvest), recent analyses suggest that chronically low levels of available soil nutrients, principally N and P, and additionally potassium (K) and boron (B) on loamy or sandy soils, are more limiting to growth in established stands than water. Fortunately for forest managers, most nutrient limitations are easily and cost-effectively ameliorated with fertilization.

Why are nutrient limitations so common in southern pine plantations? Simply, nutrient limitations develop when a stand's potential nutrient use cannot be met by soil nutrient supply (**Figure 2**). Typically, nutrient availability is rather high following harvesting and site preparation (for planting) as these disturbances provide suitable conditions for rapid decomposition and release of nutrients from the accumulated forest floor and slash material. Use of nutrients by newly-planted crop trees is minimal owing to their small size, but as trees grow, nutrient demand and use increase rapidly. Simultaneously, the supply of readily available nutrients is being rapidly sequestered within the accumulating forest floor and tree biomass. Consequently, a stand's nutrient requirement for maximum growth generally outstrips soil supply (particularly for N) near canopy closure. As the available nutrient supply diminishes, leaf area production and tree growth become limited. It is not surprising that the majority of field trials in intermediate-aged southern pine stands (from 8 to 20-years old) have shown strong responses to additions of N and P. In young stands, the development of nutrient limitations is still possible when levels of available nutrients (particularly P) in the soil are low and the soil volume exploited by roots is small. As other silvicultural treatments (e.g. vegetation control and/or tillage) are used to improve water availability, crop tree growth and use of nutrients will be increased at young ages. Fertilization will be needed to sustain rapid growth on all but the most fertile sites.

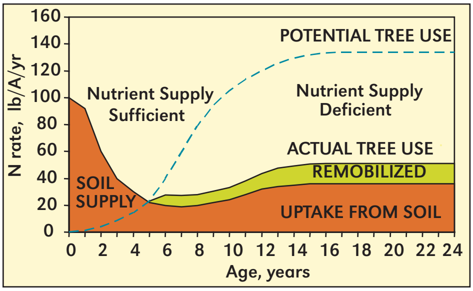

Figure 2. The concept of soil N supply and a stand's potential and actual use of N as related to stand development (age).

Fertilization as a Component of Site-Specific Silvicultural Regimes for Southern Pine Plantations

The key to optimizing leaf area, thereby increasing tree growth, is the development and implementation of site-specific silvicultural prescriptions. Forest managers now recognize that intensive plantation silviculture is like agronomy–both the plant and the soil need to be actively managed to optimize production. Silvicultural treatments must form an integrated management regime that optimizes growth throughout the life of the plantation. High quality seedlings from the best genetic families of the right species must be planted on sites prepared to ameliorate soil physical properties that limit root growth. Competing vegetation must be controlled throughout the life of the stand. Thinning is required to provide crop trees with adequate growing space as trees get larger. Improving stand nutrient supply through fertilization is a key component of intensive management regimes in southern pine plantations because nutrient limitations are very widespread.

P Fertilization at Stand Establishment

The benefits of early P fertilization on poorly drained, P-deficient Ultisols of the Atlantic and Gulf Coastal Plain have long been recognized. Volume growth gains averaging 40 to 50 ft^3/A/yr are typical on severely P-deficient sites. Because the duration of response to a single application of 50 lb P/A[1] may last for 20 or more years, P fertilization on deficient sites may yield volume gains of over 100% and consequently is viewed as an improvement in site quality. Site index gains (height of trees at age 25) of 6 to 10 ft. or more are typical when P is applied at or near time of planting. Recent results from several Forest Nutrition Cooperative (FNC) trials have shown that large areas of well-drained sites on the upper Gulf Coastal Plain are also P-deficient. Identification of stands in need of early fertilization is based on landscape position, soil type, geology, soil and foliar tests, and experience. The critical value for soil P below which a fertilizer response is expected is 6 parts per million (ppm, Mehlich-3 extraction procedure). Critical values for foliar P concentrations vary by species and range from 0.09% for slash pine to 0.11% for loblolly pine. The sources of fertilizer P that are typically used include diammonium phosphate (DAP), triple superphosphate (TSP), and rock phosphate. DAP is now the most widely used source for fertilization at time of planting. Rates of application vary from 25 to 50 lb P/A (125 to 250 lb DAP/A).

N+P Fertilization During Midrotation

By age 5 or earlier, a plantation's potential to use N and P typically outstrips the available soil supply resulting in restricted leaf area development and growth. At canopy closure, stands are generally very responsive to additions of N+P rather than P alone, as long as gross P deficiencies were corrected at or soon after planting. Results from an extensive series of intermediate-aged fertilizer trials in loblolly pine stands established by the FNC indicate that over 85% of the stands responded to N+P fertilization. Growth gains averaging 30% (50 ft^3/A/yr) over an 8-year period following a one-time application of 200 lb N/A and 25 lb P/A are typical. Responses of over 100 ft^3/A/yr are possible on some sites. For the majority of stands, additions of N+P result in much greater effects than either element applied alone (**Figure 3**). A prescription of 150 to 200 lb N/A plus 25 lb P/A is used for loblolly pine or slash pine on most sites. The growth response is proportional to the N rate applied. Lower doses of N are recommended for longleaf pine (*Pinus palustris* Mill.) to prevent aggravation of insect and disease problems.

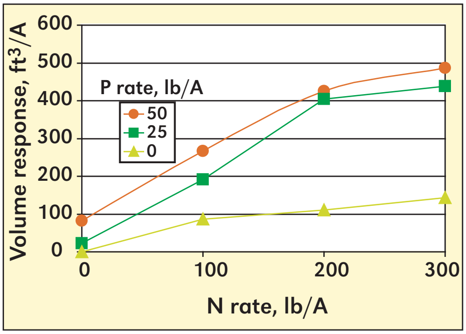

Figure 3. Eight-year cumulative growth response of midrotation loblolly pine stands to N and P fertilization in the southeastern U.S.

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[1] Note: Phosphorus fertilizer application rates are given as lb P/A in this article. To convert P to P_2O_5, multiply by 2.29.

Aerial application is used for the majority of operational fertilization in Southeast pine forests.

Financial returns from N+P fertilization of intermediate-aged stands are strongly dependent on fertilizer cost, the wood product mix (sawlog, chip and saw, pulpwood) and price that can be realized for the additional wood produced, and the number of years before harvest. Application of 200 lb N/A plus 25 lb P/A presently costs around $100/A. At this price, midrotation fertilization (between ages 8 and 15) is an attractive investment with average internal rates of return exceeding 10%. Fertilization is frequently conducted in conjunction with a first or second thinning, to maximize returns on investment. Because of the attractive financial returns that are possible, fertilization is a widespread silvicultural treatment in the Southeast. In 2004, over 1.2 million acres of pine plantations were fertilized (**Figure 4**). It is estimated that about three-fourths of operational fertilization in southeastern pine forests is by aerial application.

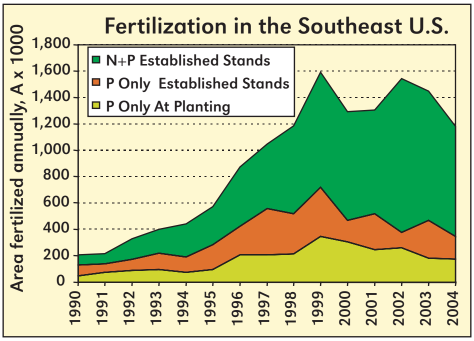

Figure 4. Area of southern pine plantations annually fertilized in the southeastern U.S. (FNC data).

Conclusion

FNC research indicates that the growth potential of southern pines planted in the southeastern states is much higher than commonly thought just a few years ago. The challenge now is to develop and implement the appropriate silvicultural systems to realize this potential in a cost-effective and environmentally sustainable manner. The FNC is aggressively pursuing several opportunities for improving plantation growth and value through the management of site resources. Additional information on the FNC work is available at the website: >**www.forestnutrition.org**<. BC

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Acknowledgments

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ARKANSAS

Long-Term Effects of Treating Poultry Litter with Alum on Phosphorus Availability in Soils

By P.A. Moore, Jr. and D.R. Edwards

Repeated use of poultry litter as a nutrient source can lead to nutrient imbalances, especially a build-up in extractable phosphorus (P). Addition of aluminum sulfate (alum) to poultry litter has been advocated as a possible means to minimize runoff loss of P from litter when applied to fields. Results from small plot studies showed that P in soils receiving aluminum sulfate–treated (alum-treated) litter was less soluble than P from normal poultry litter, and less P leaching occurred. Larger-scale paired-watershed studies showed significantly less P runoff from fields receiving alum-treated litter compared with normal litter.

Although poultry litter is considered an excellent organic nutrient source, studies have shown that litter applications can result in increased nonpoint source P runoff. When P levels in rivers and lakes are elevated, algal blooms can occur. Some algae produce compounds such as geosmin, which give water a bad taste and smell. In northeast Oklahoma and northwest Arkansas, there are several river systems, such as the Eucha/Spavinaw and Illinois River, which are experiencing water quality problems believed to be linked to excessive P loading (pollution). As a result of high P levels in Lake Eucha and Lake Spavinaw (the drinking water source for the City of Tulsa), eight poultry companies were sued in 2003 by Tulsa for nonpoint source P pollution. Although this case was settled out of court, the state of Oklahoma has recently filed a similar suit with the same companies over litter application in the Illinois River Watershed. The state of Arkansas has petitioned the U.S. Supreme Court to intervene in the case because they believe "states rights" are at stake.

Applying alum in a chicken house.

Most of the poultry farms in the Ozarks region have a sufficient land base to accept the nitrogen (N) associated with the poultry litter generated each year. However, since poultry litter has a low N:P ratio, more P is typically applied than the crops can utilize, when the litter is applied based on its N value. This excess P loading can result in a buildup of soil test P when annual litter applications are made, as well as increased P runoff risk. Most of the P in runoff from pastures fertilized with litter is soluble P, rather than particulate P. Soluble P levels in poultry litter can

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be greatly reduced if the litter is treated with aluminum sulfate (commonly referred to as alum). When the aluminum (Al) in alum binds with the P in litter, P runoff in pastures can be reduced by approximately 75%.

Alum also reduces ammonia emissions from poultry litter. Lower concentrations of ammonia in poultry barns result in a healthier environment for chickens and agricultural workers alike. Bird weight gains, feed conversion, and condemnation rates are improved when alum is used. In addition, energy costs from propane use can be decreased in winter months, since ventilation can be reduced. Reductions in ammonia emissions also result in a higher N content in the litter, which often results in higher crop yields with alum-treated litter. As a result of these benefits, over 700 million broiler chickens are grown each year in barns receiving alum treatment. The USDA Natural Resources Conservation Service (NRCS) provides cost-share support to growers for this best management practice (BMP) in several states. Likewise, many of the poultry companies provide cost-share to growers for using alum, since it improves feed conversion.

While the short-term agricultural and economic benefits of treating poultry litter with alum have been well documented during the past decade, questions often arise as to what the long-term effects of alum are on Al and P availability in soils. Moore and Edwards (2005) showed that alum-treated litter had no effect on Al availability in soils, uptake by plants, and/or in runoff water, whereas additions of ammonium nitrate (NH_4NO_3) fertilizer acidified the soil and resulted in high levels of exchangeable Al and poor forage growth.

The objectives of this study were to evaluate the long-term effects of normal poultry litter, alum-treated litter, and NH_4NO_3 on P availability in soils, P leaching, and P runoff in pastures.

Small Plot Study

A long-term study was initiated in April of 1995 on 52 small runoff plots cropped to tall fescue, located at the Main Agricultural Experiment Station of the University of Arkansas on a Captina silt loam soil (Typic Fragiudult). There were 13 treatments, including four rates of alum-treated poultry litter, four rates of untreated poultry litter, four rates of NH_4NO_3, and one unfertilized control. Litter application rates were 1, 2, 3, and 4 tons/A. Ammonium nitrate application rates were 73, 146, 219, and 292 lb N/A, and were based on the same amount of total N as with alum-treated litter added during year one. There were four replications per treatment in a randomized block design.

Applying litter to paired watersheds.

Soil samples (0 to 2 in.) were taken from each of the 52 plots (10 cores/plot) prior to the study and analyzed for Mehlich 3-P with detection by ICP (Mehlich, 1984) and water soluble P (Self-Davis et al., 2000) The extraction was a 1:7 soil:extraction solution volume ratio. The fertilizer treatments were then randomized, based on Mehlich 3-P values, so the average soil test P level for each treatment was as close as possible (within 1 mg P/kg or 1 part per million [ppm]) to the overall average of 131 mg P/kg.

Soil samples (0 to 2 in.) were also taken periodically (at least one time per year) for the duration of the study and analyzed for Mehlich 3-P and water soluble P. In April, 2002, after 7 years of applications, four soil cores were taken from each plot at the following depths: 0 to 5, 5 to 10, 10 to 20, 20 to 30, 30 to 40, and 40 to 50 cm (0 to 2, 2 to 4, 4 to 8, 8 to 12, 12 to 16, and 16 to 20 in.)

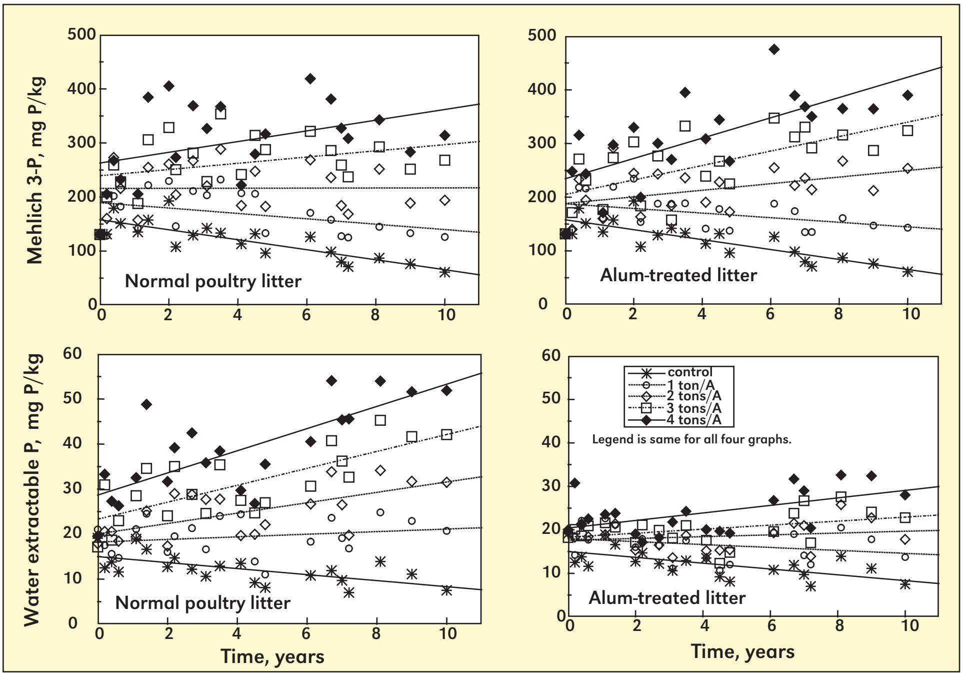

Figure 1. Mehlich 3-P and water soluble P as a function of time for various rates of normal poultry litter and alum-treated litter.

and analyzed for water soluble and Mehlich 3-P.

Trends for Mehlich 3 levels in soil for plots fertilized with alum-treated litter are shown in **Figure 1**. At application rates above 2 tons/A, Mehlich 3-P increased, whereas at rates below this it tended to decrease. These data are similar to Mehlich 3-P values in soils fertilized with normal poultry litter (**Figure 1**).

Water extractable P in soils fertilized with alum-treated litter remained relatively constant or decreased when alum-treated litter was applied at rates of 3 tons/A or less (**Figure 1**). In contrast, water soluble P values increased in soils fertilized with normal litter at rates as low as 2 tons/A (**Figure 1**). In **Figure 2**, the relationship between water soluble and Mehlich 3-P is shown. The slope of the line for normal litter is much steeper than that for alum-treated litter, indicating that for a given Mehlich 3 soil test P level, there will be more soluble P in soils fertilized with normal litter compared to alum-treated litter. This is important, because soluble P is much more subject to runoff and/or leaching reactions than Mehlich 3-P in pastures.

When applied at the same rates, normal poultry litter resulted in roughly three times more soluble P in the surface 0 to 2 in. of soil than alum-treated litter after 7

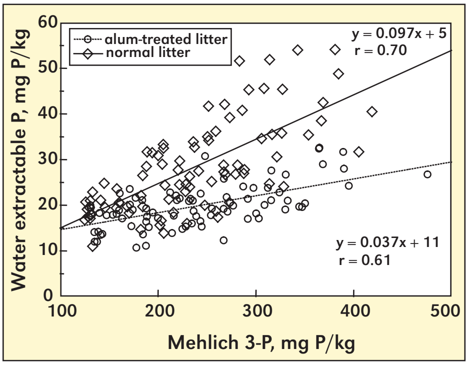

Figure 2. Relationship between water soluble and Mehlich 3 extractable P in soils fertilized with normal or alum-treated poultry litter.

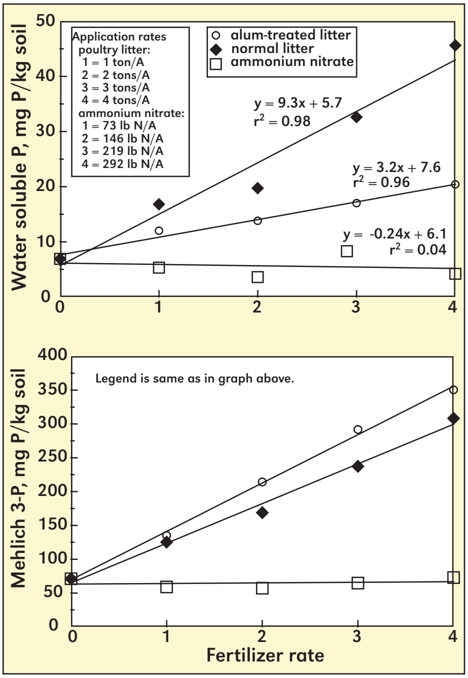

Figure 3. Mehlich 3-P and water soluble P in soil (0 to 2 in.) as a function of fertilizer application rate after 7 years of fertilization.

years of application (**Figure 3**). In contrast, the concentration of Mehlich 3-P was higher for alum-treated litter than normal litter in surface samples taken during year 7.

We hypothesized that elevated Mehlich 3-P in surface soils fertilized with alum-treated litter was related to P solubility (i.e., P from normal litter would leach down the profile because it is more soluble). In order to test this hypothesis, soil samples were taken to a depth of 20 in. during year 7. While Mehlich 3-P was slightly higher in the plots fertilized with alum-treated litter at the surface, it was higher with normal litter at the lower depths, indicating there was much more downward P movement through the profile (leaching) with normal litter than alum-treated litter (**Figure 4**). Further evidence of P leaching with normal litter was provided by the water soluble P levels, which were much higher with normal litter throughout the soil profile. This is the first report of a manure amendment reducing P leaching in soils.

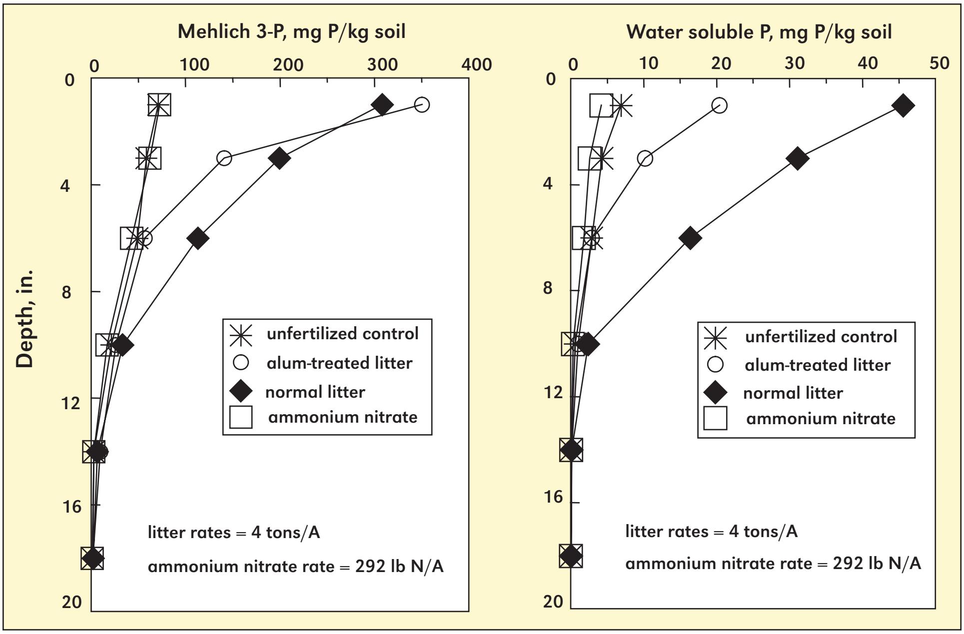

Figure 4. Mehlich 3-P and water soluble P in soil as a function of depth after 7 years of fertilization for the high rates of litter and ammonium nitrate. (Plotted as mean of sampled depth interval.)

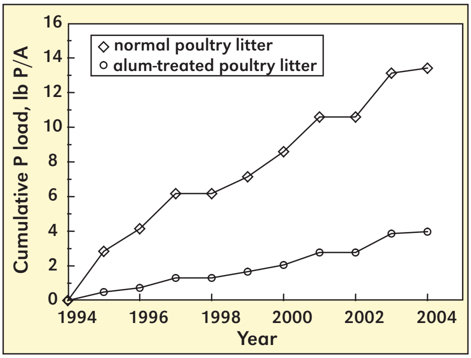

Figure 5. Cumulative soluble P loads in runoff from paired watersheds fertilized with normal and alum-treated poultry litter.

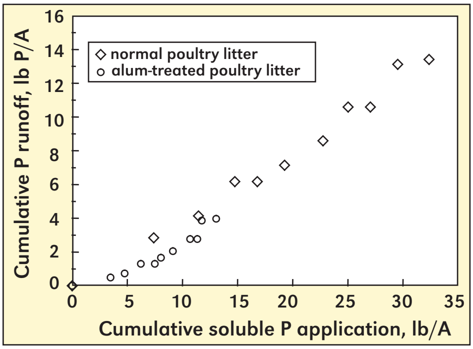

Figure 6. Cumulative P loads in runoff-paired watersheds fertilized with normal and alum-treated poultry litter as a function of cumulative soluble P applied.

Paired Watershed Study

Another long-term (20-year) study was initiated in 1994 using 1-acre paired watersheds located on a commercial broiler/beef farm in northwest Arkansas. The watersheds had earthern berms to hydrologically isolate them from surrounding land and were equipped with runoff flumes and automatic water samplers. Runoff water volumes were measured using pressure transducers connected to data loggers. Samples of runoff water from each event were analyzed for P.

The cumulative P load in runoff from normal litter was 340% higher than that from alum-treated litter (**Figure 5**). Many different studies have shown that P runoff from pastures fertilized with manure is more closely related to the amount of soluble P applied than any other variable. The Mehlich 3 extractable P in both watersheds was almost identical, indicating soil test P had little or no effect on P loading. However, when the cumulative P loads in runoff are plotted as a function of the cumulative soluble P application rate, there is a very good relationship, indicating the amount of soluble P applied is very important in controlling P runoff (**Figure 6**).

Conclusions

The results of this study indicate that the addition of alum to poultry litter is a long-term solution to the P runoff problem. Small plot studies showed P in soils from alum-treated litter was less soluble than P from normal poultry litter. The lower soluble P in alum-treated litter resulted in less P leaching than with normal litter. Likewise, paired watershed studies showed significantly less P runoff from fields fertilized with alum-treated litter. BC

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References

Mehlich, A. 1984. Mehlich 3 soil test extractant: A modification of Mehlich 2 extractant. Commun. Soil Sci. Plant Anal. 15:1409-1416.

Moore, P.A., Jr. and D.R. Edwards. 2005. Long-term effects of poultry litter, alum-treated litter and ammonium nitrate on aluminum availability in soils. J. Environ. Qual. 34:2104-2111.

Self-Davis, M.L., P.A. Moore, Jr., and B.C. Joern. 2000. Determination of water and/or dilute salt extractable phosphorus in soil. *In* Methods of Phosphorus Analysis for Soils, Sediments, Residuals, and Waters. Southern Cooperative Series Bulletin No. 396:24-26.

Information Agriculture Conference Dates Set for 2007

Here are the dates for two regional Information Agriculture Conferences and the biennial international InfoAg Conference:

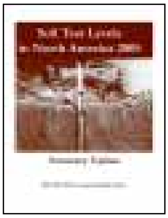
InfoAg Mid-South is scheduled for February 7-8, 2007, at the Bost Extension Center, Mississippi State University, Starkville. Back by popular demand, this regional conference will focus on the application of precision technology and information management for cotton, rice, soybeans, and other crops of interest in the Midsouth.

InfoAg Northwest is scheduled for February 20-21, 2007, at the Three Rivers Convention Center in Kennewick, Washington. This is a first-time conference in the Northwest agricultural region.

InfoAg 2007, the popular national/international edition of the Information Agriculture Conference, is set for July 10-12, 2007, at the Crowne Plaza in Springfield, Illinois. This is the same location as InfoAg 2005. Since the first conference in 1995, InfoAg has been a leading event in precision agriculture. InfoAg 2007 will present a wide range of educational and networking opportunities for manufacturers, practitioners, producers, and anyone interested in site-specific techniques and information management.

Mark your calendars and watch for more details. For further details and program updates, check the conference website >**www.infoag.org**<.

Soil Test Levels in North America, 2005



A recent publication from PPI/PPIC summarizes soil test levels for phosphorus (P), potassium (K), and pH...plus magnesium (Mg) and sulfur (S)...in North America. The summary was prepared with the cooperation of numerous public and private soil testing laboratories.

The 45-page publication—titled *Soil Test Levels in North America, 2005*—offers a snapshot view of soil test levels in the U.S. and Canada in 2005, but also provides a comparison to the previous summary which was completed in 2001.

The 8½ x 11-in. coil-bound booklet is available for purchase at US$25.00 each. An optional CD-ROM is available for US$10.00 each. It contains a PDF file showing the pages of the report, a PowerPoint file of all figures (graphs) in the report, and an Excel workbook of the major tables to facilitate construction of custom graphs for regions of interest. The combination package of the printed publication plus the CD-ROM is available for US$30.00. Shipping cost is additional.

An order form is available as a PDF file at the website: **>www.ppi-ppic.org<**. Or contact Circulation Department, PPI, 655 Engineering Drive, Suite 110, Norcross, GA 30092-2837. Phone: 770-825-8082. Fax: 770-448-0439.

World Congress of Soil Science Set for July 9-15

The 18th World Congress of Soil Science (WCSS) will take place in Philadelphia July 9-15, 2006, under the theme "Frontiers of Soil Science: Technology and the Information Age." PPI Senior Vice President Dr. Paul Fixen serves on the organizing committee and PPI/PPIC Southern Cone Program Director Dr. Fernando García is the convenor of a symposium organized jointly by the University of Nebraska and PPI addressing nutrient use efficiency and global agriculture. For further information, a link is available at: >**www.ppi-ppic.org**<.

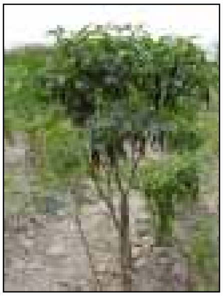
International Section

EAST ZONE INDIA

Balancing Potassium, Sulfur, and Magnesium for Tomato and Chili Grown on Red Lateritic Soil

By P. Bose, D. Sanyal, and K. Majumdar

Potassium (K) improved yield and yield attributes in tomato and chili, as well as post-harvest quality…particularly at higher K rates. In both crops, use of potassium magnesium sulfate ($K_2SO_4 \cdot 2MgSO_4$) in conjunction with potassium chloride (KCl) proved superior to using KCl alone.



Soil-test based fertilization can support India's chili productivity.

West Bengal map showing the field study locations.

The importance of tomato as a vegetable crop is reflected in its large-scale cultivation in the world. Tomato is grown on about 4.5 million hectares (M ha) worldwide, the largest producer being China with 32 million metric tons (M t). India produces about 7.6 million M t of tomatoes from about 540,000 ha, an average productivity of 14 t/ha…or about half of the world average. High-yielding tomato production requires good nutrient management.

Phosphorus (P) is especially essential for early growth and root development, while nitrogen (N) and K are fundamental in ensuring normal growth and production of quality fruit.

Adequate K can enhance fruit quality by influencing sugar levels, as well as fruit ripening and storage characteristics. Soil K deficiency can lead to uneven, blotchy ripening, high levels of internal white tissue, yellow shoulder, decreased lycopene, and irregular shaped and hollow fruits. Tomato has a relatively high K requirement compared to N, with over 300 kg K_2O needed throughout the season. Demand for K is highest during fruit bulking. About 2.6 to 3.6 kg of K is required for each 1,000 kg of harvested tomato.

District-wise productivity varies considerably from 312 kg/ha to 1,576 kg/ha. Soil test-based nutrient applications are necessary to improve productivity.

Though considerable information has been accumulated on nutrient management in tomato and chili, attempts to maximize yield in nutrient-depleted red lateritic soils have been meager. The study reported here compared growth, yield, and yield attribute responses of tomato cv. S-120 and chili cv. Phule Jyoti to treatments relying solely on KCl vs. a combination of KCl + $K_2SO_4 \cdot 2MgSO_4$. The latter source is a naturally occurring mineral, recently included in the Fertilizer

Control Order of India. It contains 22% K_2O, 11% Mg, and 22% S in sulfate form.

The experiment was located on a farmer's field in the sub-humid lateritic belt of West Bengal. Selected soil characteristics include: pH, 6.6; organic matter, 0.7 %; cation exchange capacity (CEC), 10.4 meq/100cm^3; available N, P, and K were 97.2 kg/ha, 93.8 kg/ha, and 108.6 kg/ha, respectively. Rates of K allocated to tomato and chili are outlined in **Tables 1 to 4.** Potassium chloride was used in treatments T_1 to T_5, while T_6 used a combination of KCl + $K_2SO_4{\cdot}2MgSO_4$. In tomato, T_6 split the 190 kg K_2O/ha rate between 22 kg/ha as $K_2SO_4{\cdot}2MgSO_4$ and 168 kg/ha as KCl. In chili, T_6 split 150 kg K_2O/ha between 11 kg/ha as $K_2SO_4{\cdot}2MgSO_4$ and 139 kg/ha as KCl. A uniform rate of 150-80 kg N-P_2O_5/ha was applied to all plots. The full quantity of P was applied at transplanting, while N and K quantities were split between transplanting and 45 days after transplanting. Recommended cultural practices and plant protection measures were used throughout the experiment. Chemical analyses of harvested fruits were performed according to A.O.A.C. (1984).

Tomato – Plant height measurements taken at flowering failed to detect significant differences among treat-

Table 1. Effect of K treatment on growth and flowering of tomato.

Treatment, kg K_2O/ha	Plant height, cm	Basal girth, cm	Days till 50% flowering	Truss/plant	Fruit set/truss
T_1 - 110[1]	59.5	4.2	43.0	15.0	2.8
T_2 - 130[1]	58.3	4.0	45.0	16.6	2.8
T_3 - 150[1]	63.1	4.4	45.0	17.3	2.6
T_4 - 170[1]	67.6	4.4	42.3	18.6	1.7
T_5 - 190[1]	70.1	4.6	42.6	20.6	2.7
T_6 - 190[2]	77.9	4.8	40.0	24.0	3.5
C.D.*, p=0.05	5.5	0.3	2.5	2.1	NS

[1] Denotes K supplied as KCl. [2] Denotes K supplied as $K_2SO_4{\cdot}2MgSO_4$ + KCl.
*Critical Difference

Table 2. Effect of K treatment on yield and quality of tomato.

Treatment, kg K_2O/ha	Fruit weight, g	Yield, t/ha	TSS (° Brix) at 14 days,	Ascorbic acid at 14 days, mg/100g juice
T_1 - 110[1]	64.4	30.9	4.12	221.2
T_2 - 130[1]	78.4	32.8	5.72	273.7
T_3 - 150[1]	87.7	34.0	5.12	318.7
T_4 - 170[1]	88.8	35.5	4.72	356.2
T_5 - 190[1]	95.0	37.5	4.31	217.5
T_6 - 190[2]	102.8	44.1	5.31	277.3
C.D.*, p=0.05	2.6	5.8	0.014	12.7

[1] Denotes K supplied as KCl. [2] Denotes K supplied as $K_2SO_4{\cdot}2MgSO_4$ + KCl.
*Critical Difference

Table 3. Effect of K treatment on vegetative growth and fruit bearing behavior of chili.

Treatment, kg K_2O/ha	Plant height, cm	Branches /plant	Flowers /cluster	Clusters /plant	Fruits /cluster
T_1 - 70[1]	41.9	6.8	5.2	16.7	2.7
T_2 - 90[1]	46.4	6.5	5.2	17.3	2.7
T_3 - 110[1]	51.8	6.3	5.3	18.9	2.8
T_4 - 130[1]	57.3	6.5	5.7	21.3	3.2
T_5 - 150[1]	58.8	8.0	6.0	22.0	3.3
T_6 - 150[2]	65.1	8.7	6.8	23.1	3.8
C.D.*, p=0.05	2.25	0.76	0.46	1.79	0.44

[1] Denotes K supplied as KCl. [2] Denotes K supplied as $K_2SO_4{\cdot}2MgSO_4$ + KCl.
*Critical Difference

Table 4. Effect of K treatment on yield attributes and yield of chili.

Treatment, kg K_2O/ha	Fruit length, cm	Fruit weight, g	Seeds /fruit	Green fruit yield, t/ha
T_1 - 70[1]	4.2	1.2	28.3	3.8
T_2 - 90[1]	4.8	1.4	33.0	4.5
T_3 - 110[1]	4.7	1.5	36.6	5.4
T_4 - 130[1]	5.2	1.5	41.7	7.3
T_5 - 150[1]	5.3	1.6	47.9	9.8
T_6 - 150[2]	6.0	1.9	57.0	11.6
C.D.*, p=0.05	0.58	0.06	2.69	1.14

[1] Denotes K supplied as KCl. [2] Denotes K supplied as $K_2SO_4{\cdot}2MgSO_4$ + KCl.
*Critical Difference

ments. However, differences did appear prior to harvest and as a result crop height was highest under T_6 (**Table 1**). The basal girth of plants was also influenced by K fertilization and was equally greatest under T_6 or T_5. The effect of K rate or source on branch numbers per plant was not strongly apparent. Fewest days until 50% flowering was also achieved under T_6, as was the maximum number of flowers per truss, and the maximum number of trusses per plant. Differences in fruit set per truss were not significant.

Potassium has important quality benefits for tomato.

Tomato fruit weight and yield were highly dependent on K rate. However, the combined K source treatment (T_6) supported much higher fruit weight and yield compared to T_5, which provided the same rate of K as KCl alone (**Table 2**). Measurements of fruit weight during storage noted largest losses as a result of the T_5 treatment. Total soluble solids (TSS) in freshly harvested tomatoes varied to a small degree and fruits from T_6 had the highest initial measurements. Differences in TSS become more pronounced among treatments after 14 days of storage, but no clear trends could be related back to K rate or source. Higher K application rates appeared to stimulate acid accumulation in freshly harvested fruits. However, once fruits were stored, acid contents failed to follow any clear trend related to K fertilization. However, T_5 and T_6 did produce fruits with the lowest acid content after two weeks of storage. Ascorbic acid levels increased under storage. After 14 days, concentrations were found to increase steadily up to 170 kg K_2O/ha (T_4), then decrease sharply under the highest K application rate.

Chili – Potassium had a definite role in promoting vegetative growth of chili (**Table 3**). Plant height, branches per plant, flowers per cluster, rate. Yet, as was observed in tomato, an advantage for T_6 which provided 150 kg K_2O/ha split between $K_2SO_4{\cdot}2MgSO_4$ + KCl, was observed for nearly all these growth parameters. Percent fruit drop was not significantly affected by K application rate despite a trend suggesting otherwise. Individual chili fruit length, weight, and seeds contained within all increased with K rate, but once again T_6 produced the longest and heaviest fruits, with the highest number of seed per fruit (**Table 4**). Green fruit yield showed the same trend. Thus, compared to T_5, approximately 30% more green yield was obtained by substituting a portion of K in the form of $K_2SO_4{\cdot}2MgSO_4$. BC

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References

A.O.A.C. 1984. Official Methods of Analysis of the Association of Official Analytical Chemists. Washington, D.C.

Potassium Budgets in Rice Cropping Systems with Annual Flooding in the Mekong River Delta

By Nguyen My Hoa, B.H. Janssen, O. Oenema, and
A. Dobermann

Potassium (K) balances provide crucial information for assessment of fertilizer needs and sustainability of rice cropping systems.

Potassium input-output balances constructed for wetland rice in Asia often include only a few, selected aspects of a full K budget such as fertilizer K as input and the amount of K removed by the crop as output (e.g. Patnaik, 1978; Bajwa, 1994; Dobermann, et al., 1996). In this study, we use a complete K budgeting approach to assess K inputs from sedimentation by annual flooding in double- and triple-crop systems of the Mekong River Delta in South Vietnam (**Figure 1**), which supplies about 50% of Vietnam's rice (Maclean et al., 2002). Rice is grown on alluvial soil concentrated along the banks of the Mekong and Bassac rivers (30% of the area), acid sulfate soils (45%), and coastal saline soils (20%). About 70% of the rice is grown with irrigation, the rest under rainfed conditions. The area with two rice crops per year is about 1.3 million hectares (M ha), and three crops are grown on about 0.4 M ha. The water depth of annual floods is greatest in the north of the river delta, while the south is less affected (**Figure 1**). The sediment load largely depends on the source of flood water and is greatest if the flood is caused by an overload of the two branches of the Mekong River. Sedimentation is also influenced by distance from the river.

The Nutrient Budgeting Approach

Potassium budgets were quantified for a soil-plant system at the field scale. The most relevant inputs (IN) and outputs (OUT) for K in rice cropping systems of the region are listed in **Table 1**. Particular emphasis is given to available and non-available K fractions when constructing K balances with inputs from fertilizer, rain, irrigation water, sediments, and outputs or removal via harvested products, residues, leaching, erosion, and water runoff.

It was assumed that K inputs from chemical fertilizers, rain water, and irrigation water were soluble. For simplicity, OUT 1-3 and 5 were also considered 'soluble'. Sediment-K of IN 4 and OUT 4 was characterized

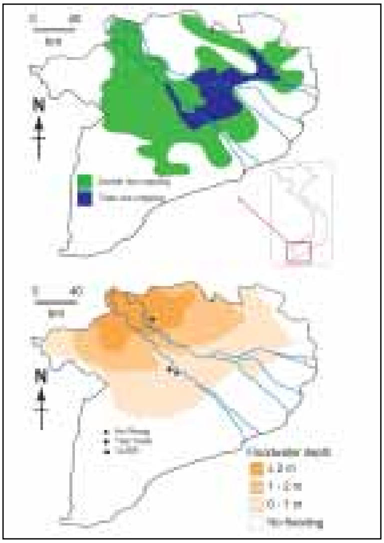

Figure 1. Water depth during annual flooding (bottom) and distribution of double- and triple-rice cropping systems (top) in the Mekong River Delta, South Vietnam. Redrawn with permission from Cantho Univeristy and the Cuu Long Rice Research Institute.

according to the three extraction methods used in this study: 1) K(NH_4OAc) extracted by 1 M NH_4OAc at pH 7 and at a soil to water ratio of 1:20 at one hour shaking time, 2) K(NaTPB) extracted by 0.2 M sodium tetraphenyl borate (NaTPB) during 5 min incubation (Cox et al., 1999), and 3) K(total) determined by a mixture of concentrated HF and $HClO_4$. This resulted in four K balances:

- KBAL(soluble) = (IN1 +IN2 + IN3) – (OUT 1 + OUT 2 + OUT 3 + OUT 5)
- KBAL(NH_4OAc) = KBAL(soluble) + IN 4 K(NH_4OAc) – OUT 4 K(NH_4OAc)
- KBAL(NaTPB) = KBAL(soluble) + IN 4 K(NaTPB) – OUT 4 K(NaTPB)
- KBAL(total) = KBAL(soluble) + IN 4 K(total) – OUT 4 K(total)

Experimental Fields and Research Methodology

The experimental sites differed in cropping intensity, sedimentation inputs, crop residue management, and fertilizer K rates (**Table 2**).

Table 1. Inputs and outputs of K for rice cropping systems in the Mekong Delta, as considered in this study.

Code	Description
Inputs	
IN 1	Chemical fertilizer
IN 2	Rain water
IN 3	Irrigation water
IN 4	Sedimentation via annual floods
Outputs	
OUT 1	Harvested products
OUT 2	Removed crop residues
OUT 3	Leaching
OUT 4	Erosion
OUT 5	Run off water

Table 2. Cropping systems at the experiment site, including: 1) a long-term experiment at the Cuu Long Rice Research Institute, CLRRI, Omon, and 2) a farmer's field at An Phong, Omon, Cantho province, and 3) a farmer's field at Thoi Thanh, Dong Thap province. NP = treatment receiving fertilizer N and P, NPK = treatment receiving fertilizer N, P, and K.

Site	Treatment	Annual crops	Sediment inputs	Residue management	K fertilizer application
CLRRI	NP	rice-rice	Low	Removal	none
CLRRI	NPK	rice-rice	Low	Removal	high
An Phong	NPK (farmer's field)	rice-rice	High	Incorporation after dry season crop, partially removed in other crops	moderate
Thoi Thanh	NPK (farmer's field)	rice-rice-rice	High	Incorporation after dry season crop, partially removed in other crops	low

The input by chemical fertilizer (IN 1) is the amount of fertilizer K applied per hectare to each crop. Rainwater samples (IN 2) were collected and soluble K in rain water was measured. The amount of rainfall was obtained from weather stations. Irrigation water samples (IN 3) were taken from the canal feeding the fields and the quantity of irrigation water brought into the experimental area was derived from the change in water level before and after each irrigation event. Inputs via sediment in irrigation and floodwater (IN 4) were measured as suspended sediment in irrigation water samples, and sedimentation during the flooding period from mid-July to December was determined using sediment traps. The outputs or removal of K with rice grain, straw, and stubble (OUT 1 and 2) were determined from crop cuts and K concentrations in plant materials. Leaching (OUT 3) was assessed by determination of K in soil solution and in situ measurements of the vertical percolation under flooded conditions.

Estimates of sediment-K losses (OUT 4) via drainage or sediment removal from irrigation canals by farmers were obtained by farmer interviews. The sediment removal

Table 3. Potassium fractions and K inputs with sediments during flooding periods of 2000 and 2001 at CLRRI, An Phong, and Thoi Thanh.

Sediment characteristics	CLRRI	An Phong	Thoi Thanh
K fractions in sediments			
K(NH$_4$OAC), mmol/kg	4.62-4.63	2.31-2.66	2.07-3.09
K(NaTPB), mmol/kg	11.67-16.00	10.81-14.25	10.83-16.79
K(total), mmol/kg	459-475	526-557	538-556
Sediment thickness, weight, and K inputs			
Thickness, mm	8.8-16.6	19.8-22.2	20.2-30.0
Sediment weight at 40°C, t/ha	17-40	76-94	90-178
Input of K(NH$_4$OAc), kg/ha	3-7	7-10	10-21
Input of K(NaTPB), kg/ha	11-18	42-40	59-75
Input of K(total), kg/ha	320-710	1,651-1,926	1,892-3,868

was calculated based on information on canal size and depth, and the time of sedimentation.

In irrigated rice fields, water run-off (OUT 5) may occasionally occur from August to November (mainly in flood periods) due to heavy rains. It was not measured in this study.

The K concentration in rain water (IN 2) ranged from 0.3 to 3.3 mg/l. The K input from rain water ranged from 6 to 10 kg/ha/year, with rainfall averaging 1,461 to 1,911 mm. The K concentration in irrigation water (IN 3) ranged from 1.5 to 2.5 mg/l. The K input with irrigation water ranged from 4 to 12 kg/ha, depending on the amount of irrigation water, ranging from 250 to 500 mm at the three sites. The sediment content of the irrigation water was small ranging from 11 to 500 mg/l across sites so that sediment-K inputs with irrigation water (IN 4) were negligible and thus neglected. Sediment inputs during the annual flooding period, however, were substantial and K inputs with different fractions (IN 4) are provided in **Table 3**.

Removal of K with grain (OUT 1) was ≤ 10 kg/ha when yield was ≤ 5 t/ha and about 20 kg/ha when yield ranged between 6 to 7 t/ha. Straw-K content ranged from 39 to 118 kg/ha depending on yield level and K nutrition of the crop. Stubble-K ranged from 12 to 50 kg/ha. Potassium removal with crop residues (OUT 2) was calculated according to the residue management at each site. Average K concentrations in the soil solution at the three sites ranged from 0.52 to 6.4 mg/l. Water percolation rate ranged from 0.3 mm to 1.5 mm/d, which is a typical percolation rate in rice fields with a hardpan. Total K loss due to percolation (OUT 3) was small (<1 to 2 kg/ha). At Thoi Thanh, the sediment fraction in drainage water (OUT 4) after soil puddling was very small (1.8 g/l) and therefore neglected for the K balance. Calculated K loss from sediment removal in the form of K(NH$_4$OAc), K(NaTPB) and K total were 4, 21, and 681 kg/ha/year, respectively. As in Thoi Thanh, sediment losses at An Phong were estimated with 35% of the sediment inputs.

K budgets in double- and triple-rice crop systems with annual flooding. The annual K budgets of the double and triple rice cropping systems at the experimental sites are given in **Table 4**. The analysis across sites showed K inputs with rain and irrigation water of 21 to 24 kg K/ha annually. The balance of K (soluble) ranged from +44 to -86 kg K/ha and was largely influenced by fertilizer K application and residue management, and to a lesser extent by K removal with harvested products. Removal of straw residues formed a major output of K (**Table 4**).

Table 4. Annual K budgets in double- and triple-rice cropping system in CLRRI, An Phong, and Thoi Thanh.

		CLRRI			
Parameter	K input, output, balance	NP	NPK	An Phong	Thoi Thanh
		---------- kg/ha/year ----------			
K(soluble)	IN 1: Chemical fertilizer	0	150	70	40
	IN 2: Rain water	6	6	10	6
	IN 3: Irrigation water	18	18	14	15
	Σ IN 1-3: Total input	24	174	94	61
	OUT 1: Harvested product	13	15	31	45
	OUT 2: Removed residues	79	113	68	100
	OUT 3: Leaching	1	2	2	2
	Σ OUT 1-3: Total output	93	130	101	147
	KBAL(soluble)	-69	44	-7	-86
K(NH$_4$OAc)	IN 4: Flood water sediments	3	3	7	10
	Σ IN 1-4: Total inputs	27	177	101	71
	OUT 4: Sediment loss	0	0	3	4
	Σ OUT 1-4: Total output	93	130	104	151
	KBAL(NH$_4$OAc)	-66	47	-3	-80
K(NaTPB)	Sediment in flood water	11	11	42	59
	Total input (Σ INs 1-4)	35	185	136	120
	Sediment loss	0	0	15	21
	Total output (Σ OUT 1-4)	93	130	116	168
	KBAL(NaTPB)	-58	55	20	-48
K(total)	Sediment in flood water	320	320	1,651	1,892
	Total input (Σ IN 1-4)	344	494	1,745	1,953
	Sediment loss	0	0	594	681
	Total output (Σ OUT 1-4)	93	130	695	828
	KBAL(Total)	251	364	1,050	1,125

Other outputs were relatively small, except when farmers remove sediment to allow gravity irrigation. Percolation loss in these clay soils was small, because of the presence of hardpans and the puddling practice. Losses via leaching may be negligible for clay soils.

Annual flooding supplied substantial amounts of K through sedimentation, but there were large differences in K inputs among K fractions. Newly deposited sediments from annual flooding supplied small amounts under 10 kg K(NH$_4$OAc)/ha, small to moderate amounts of 11 to 59 kg K(NaTPB)/ha, and very large amounts of 320 to 1,890 kg mineral K(total)/ha depending on the rate of sedimentation. It can be assumed that K(NH$_4$OAc) is more readily available to the rice crop, while K(NaTPB) and K(total) would largely effect the long-term supply of indigenous K supply. Sediment K inputs clearly need to be considered in the calculation of K budgets and long-term K fertilizer requirements, where annual flooding occurs in the Mekong River Delta of Vietnam.

Balances of K(soluble) were strongly influenced by K fertilizer application. In treatments without K application at CLRRI, where sediment deposition was less than 50 t per ha and year, balances were negative for K(soluble), K(NH$_4$OAc), and K(NaTPB), but positive for K(total). The negative balance of K(soluble) was reversed with the application of 150 kg K/ha in NPK treatments, hence balances of K(NH$_4$OAc), and K(NaTPB) were reversed accordingly. At An Phong, fertilizer K inputs of 70 kg/ha resulted in neutral or slightly positive K balances for the above mentioned fractions, while the application of 40 kg fertilizer K/ha in the triple-rice cropping system at Thoi Thanh was insufficient to prevent negative soluble K. There was a net input of 3-7 kg K(NH$_4$OAc)/ha and 11 to 38 kg K(NaTPB)/ha with sediments. Evidently, the differentiation between available and non-available K is important, especially when the inputs of initially non-available forms supply substantial amounts of K to the plants. Sediment-K inputs of the K (total) fraction were substantial and by far exceeded K inputs from all other fractions.

Conclusion

We conclude that the partial budgeting approach is inadequate for an accurate estimation of K balances in rice cropping systems with substantial annual flooding in the Mekong Delta of Vietnam. The annual K input with rain and irrigation water supplies about 20 to 25 kg K/ha or 10% of the plant K uptake requirements in a double-rice cropping system (i.e. 200 kg plant K/ha for two rice crops each yielding 6 to 7 t/ha), while crop residue removal after harvest is about 70 to 90% of plant K at harvest. Less negative K balances are expected where crop residues are fully recycled. Sedimentation in areas with annual flooding provides substantial amounts of not-immediately-available mineral K and plays an important role in the maintenance of long-term supply of K in the system. Long-term fertilizer K requirements in areas with long periods of flooding and sedimentation should not be based on partial nutrient budgets. Constructing adequate K budgets under such conditions should include the measurement of available and non-available K. Potassium omission or addition plots should be used to verify fertilizer K requirements in cases of uncertainties. Negative K balances and larger yield responses to fertilizer K application can be particularly expected in regions of the Mekong River Delta where cropping intensity is high, and annual flooding is absent or restricted to short periods with little sedimentation. BC

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References

Bajwa, M.I. 1994. Potash Review No. 3/1994. Subject 1, 20th Suite. International Potash Institute, Basel, Switzerland.

Cox, A.E., B.C. Joern, S.M. Brouder, and D. Gao. 1999. Soil. Sci. Soc. Am.J. 63: 902-911.

Dobermann, A., P.C. Sta. Cruz, and K.G. Cassman. 1996. Nutr. Cycl. Agroecosyst. 46: 1-10.

Maclean, J., D. Dawe, B. Hardy, and G.P. Hettel (eds.) 2002. Rice Almanac. Los Baños, Philippines, International Rice Research Institute (IRRI); Bouaké, Côte d'Ivoire,, West Africa Rice Development Association; Cali, Colombia, International Center for Tropical Agriculture; Rome, Italy, Food and Agriculture Organization. 253 p.

Patnaik, S. 1978. *In* Soils and rice. International Rice Research Institute, Los Baños, Philippines. p. 501- 520.

Improvement of Soil Nutrient Management via Information Technology

By Hongting Wang, Ji-yun Jin, and Bin Wang

Site-specific nutrient management (SSNM) can increase incomes in small, family field plot-scale systems through the identification of soil variability and implementation of rational nutrient application.

Precision agriculture plays an important role in crop production and environmental protection. However, in Shanxi Province, where each farm family is assigned to operate one, or several, small field plots with an average size of 0.1 to 0.2 ha, farmers' fertilizer decision-making processes are commonly limited due to little understanding of soil nutrient status or spatial variability of their small field plots. It is also difficult to study the spatial variability of soil nutrients and develop the variable rate techniques under such circumstances in developing countries (Jin, 1998). This study was conducted in the monitored village of Ershilipu, in Xinzhou City, to develop an approach to meet the needs of SSNM for these farming systems.

At the SSNM study site with maize at vegetative stage, Mr. Bin Wang compares growth with farmers' practice (at left) and recommended fertilization (right).

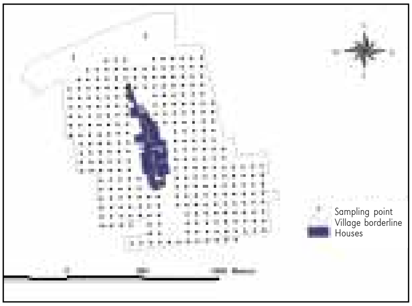

Figure 1. Distribution of sampling points at experiment site.

Maize is a major crop in Shanxi, with planted area of 915,450 ha and an average yield of 5.21 t/ha. The local climate at the experiment site is semi-arid monsoon, with an average annual rainfall of 405 mm, an average temperature of 8.5 °C, and a frost-free period of about 160 days. The soil type is a poorly drained alluvial classified as Fluvo-aquic.

A total of 280 soil samples from 0 to 20 cm depth were collected using a 100×100 m grid during March 2000 (**Figure 1**). Soil nutrients were determined according to procedures applied by the National Laboratory of Soil Testing and Fertilizer Recommendation... formerly called the Chinese Academy of Agricultural Sciences (CAAS)-PPIC Cooperative Soil and Plant Analysis Laboratory. Farmers' field plot distribution was mapped with a TOPCON geodesic apparatus (**Figure 2**) and soil nutrient maps were developed by ArcView Geographic Information System (GIS) 3.2. Ten field plots were selected with a differential global positioning system (DGPS) to monitor the effect of SSNM and guide soil fertility management and fertilization.

Results in **Table 1** show that soil properties of the site varied greatly. Coefficients of variation (CV) were greatest for available ammonium-nitrogen (NH_4^+-N), phosphorus (P), and organic matter (OM) at 68%, 46%, and 48%, respectively. Many researchers have pointed out that soil parent materials, vegetation, till-

Table 1. Statistical feature of selected soil properties at experiment site.

	pH	OM, %	K, mg/L	NH_4^+-N, mg/L	P, mg/L
Maximum	8.2	0.83	136.9	30.4	42.3
Minimum	7.7	0.03	46.9	0.1	1.1
Mean	8.0	0.22	88.3	8.3	8.3
Standard deviation	0.1	0.10	16.6	5.7	3.8
CV, %	1.2	47.5	18.8	67.9	46.0
Critical value			78	50	12
Percentage[1]			22.9	100	86.4

[1] The ratio between number of samples below critical value and the total sampling number.

age, fertilization, cropping history, and other factors, can influence the variability of the physical and chemical properties of fields (Carr et al., 1991; Bouma and Finke, 1993). A survey of farmers' fertilizer use for the maize cropping system in 2003 indicated that N and P were widely applied with the average being 200 kg N/ha (CV of 43%) and 121 kg P_2O_5/ha (CV of 70%), respectively. Potassium (K) and micronutrients were commonly ignored in this system. Large differences in fertilization practice are likely a major cause of soil variability. In turn, the smaller spatial variability for soil K (CV of 19%) may be related to little K input within the region. The average soil test levels for NH_4^+-N, P, and K were 8.3 mg/L, 8.3 mg/L, and 88.3 mg/L, respectively. The percentage of samples below critical values were 100% for NH_4^+-N, 86% for P, and 23% for K.

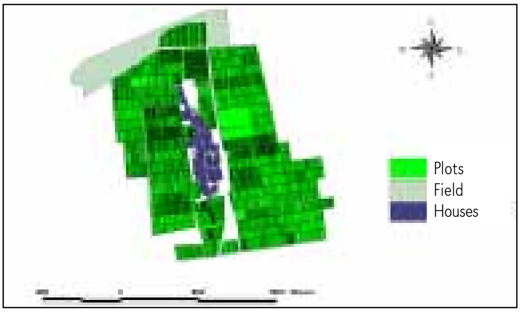

Figure 2. Distribution of farmer plots at experiment site.

Contoured soil property maps may directly reflect the spatial distribution characteristics of soil nutrient elements (**Figures 3** and **4**). Maps of soil nutrient status for each small field plot were obtained on GIS by overlaying the contour map of soil nutrients with a distribution map of farmers' fields. Phosphorus was deficient in most of the site, excluding a small area adjacent to greenhouses that had available P above 13 mg/L. This is closely related to higher input of organic manure and P fertilizers on vegetable crops grown under greenhouses. Soils deficient in P (7 to 13 mg/L) were normally found in the western region of the village where maize is largely grown with insufficient supply of P fertilizer. The most severe P deficiency (less than 7 mg/L) occurred along top and bottom edges on the east side of the village due to little fertilizer input and sandy soil texture. Soil K fertility followed a simi-

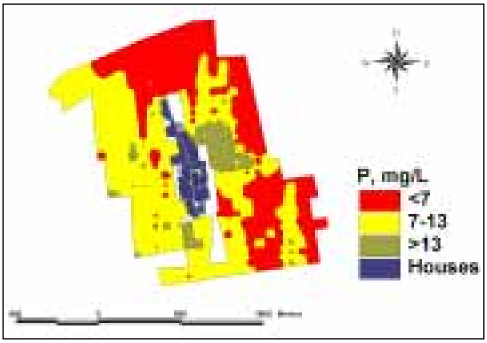

Figure 3. Distribution of soil P at experiment site.

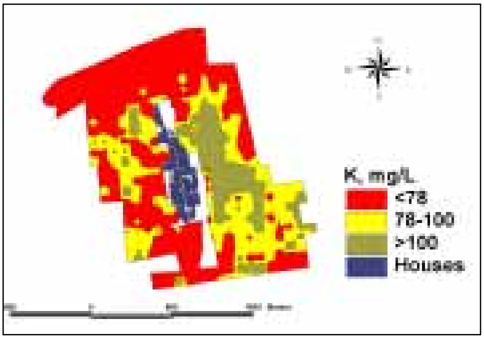

Figure 4. Distribution of soil K at experiment site.

Table 2. Responses of maize yield and net income to SSNM.

	Yield, kg/ha			Net income, US$/ha		
Field No.	Farmers' practice	SSNM practice	Increase, %	Farmers' practice	SSNM practice	Increase, %
1	7,470	8,250	10.4	983	1,052	7
2	6,975	7,815	12.0	909	978	8
3	9,015	9,495	5.3	1,215	1,230	1.2
4	9,465	10,590	11.9	1,283	1,401	9
5	7,170	7,935	10.7	938	1,005	7
6	8,100	10,125	25.0	1,078	1,324	23
7	9,045	10,815	19.6	1,220	1,437	18
8	10,575	11,175	5.7	1,449	1,482	2.3
9	8,190	9,165	11.9	1,091	1,180	8
10	7,545	8,430	11.7	995	1,070	8
Average	8,355	9,380	12.4	1,116	1,216	9

lar trend, thus P and K spatial distribution are both closely related to fertilization history and soil texture (**Figure 4**).

At jointing stage, difference in growth with the check (farmers' practice) and recommended fertilization (right) are apparent.

Farmers are inherently interested in these maps due to the visual description of soil nutrient status of their fields. Maps are used by villagers to guide their fertilization. Fertilizer recommendations are provided for each plot and farmer using Systematic Approach technology, which was developed by Dr. Arvel Hunter, Agro Services International Inc., and introduced to China in 1988. Variable SSNM fertilization is subsequently applied by hand. Field growth under SSNM was more vigorous compared to common farmer practice (see photos). Final results also showed that recommended SSNM fertilization significantly increased maize yield and net income compared to common practice (**Table 2**). Maize yield increased by 5 to 25% with an average yield increase of 1,025 kg/ha, or 12%; net income improved by 1 to 23% with the average increase being US$100/ha, or 9%.

Summing up, large spatial variability existed for soil properties measured in this monitored village. Greater variability occurred for soil NH_4^+-N, P, and OM, while soil K had smaller spatial variability–a reflection of the relative intensity and history of fertilizer use. These results support the use of SSNM to help farmers produce higher yield and income with rational fertilization. BC

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References

Jin, Ji-yun. 1998. Precision agriculture and its prospects in China. Plant Nutrition and Fertilizer Science. 4(1):1-7 (In Chinese).

Carr, P.M., G.R. Carlson, J.S. Jacobsen, G.A. Nielsen, and E.O. Skogley. 1991. Farming soil, not fields: A strategy for increasing fertilizer profitability. J. Prod. Agric. 4:57-61.

Bouma, J. and P.A. Finke. 1993. Origin and nature of soil resource variability. *In* Robert, P.C., R.H. Rust, and W.E. Larson (eds). Soil Specific Crop Management, Madison, Wisconsin, ASA-CSSA-SSSA, p.3-14.

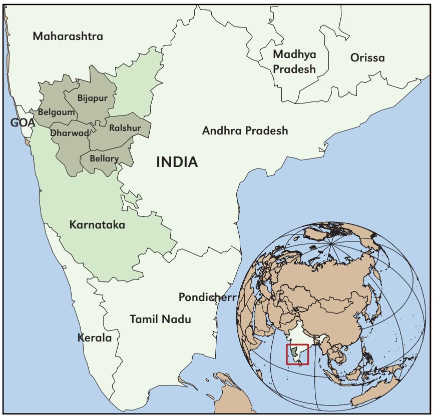
Site-Specific Nutrient Management for Maximization of Crop Yields in Northern Karnataka

By D.P. Biradar, Y.R. Aladakatti, T.N. Rao, and K.N. Tiwari

On-farm rice, wheat, and chickpea demonstrations conducted across the region show substantial increases in yields and economic returns compared to recommended and common fertilization practices... which lead to stagnant and reduced food production.

Karnataka is predominantly an agrarian state of south India with nearly 71% of its population depending on agriculture and related activities which accounts for half of the state's economy. It has varied agro-climatic conditions and topographical features with diversified crops and cropping systems. Karnataka state is comprised of 10 agro-climatic zones based on soil types, rainfall pattern, and crops grown. Among these, the northern dry zone is the largest, encompassing the majority of northern Karnataka and is comprised of Bijapur, Bellary, and parts of Raichur, Dharwad, and Belgaum Districts. This is a relatively dry zone, receiving about 465 to 790 mm of annual rainfall. Soils primarily consist of deep, medium, and shallow Vertisols (black soils).

Northern Karnataka has well diversified cropping including rice, cotton, maize, and chili (red pepper) during *kharif* season, and wheat, chickpea, sorghum, and sunflower during *rabi* season. Only 13% of the area is currently irrigated. Rice is mainly grown in the Bellary District under the Tungabhadra irrigation project and the remaining crops are scattered over all districts both under rainfed and irrigated ecosystems. The productivity of important crops like rice, wheat, and chickpea is low if compared with state and national averages, showing potential for yield improvements (**Table 1**). Productivity is low as a result of imbalanced usage of major nutrients and under-fertilization without assessing the available nutrient status of soils.



District-level map of the Northern Karnataka region.

A research project was initiated during 2003-04 to study the effect of site-specific nutrient management (SSNM) on productivity of important crops of Northern Karnataka, and to disseminate the knowledge to surrounding farming communities. Research and demonstration trials were undertaken on farmers' fields. Five trials each on rice, wheat, and chickpea were

Table 1. Yield gaps (2001-02) in Northern Karnataka.

		Average productivity, t/ha		
Crop	Cropping area, ha	Northern Karnataka	Karnataka	National
Wheat	147,500	0.82	0.80	2.77
Rice	308,600	2.18	2.40	2.09
Chickpea	181,200	0.51	0.62	0.87

Source: Fertilizer & Agricultural Statistics, Southern Region (2002-03), FAI, New Delhi.

Table 2. Comparison of nutrients applied within the three fertilizer use strategies.

		Application rates, kg/ha							
		N	P_2O_5	K_2O	S	Zn	Cu	Mn	Fe
Wheat–SSNM goal of 4 t/ha	SSNM	125	100	50	25	10	10	5	10
	RDF	100	75	50	-	-	-	-	-
	FP	100	50	30	-	-	-	-	-
Rice–SSNM goal of 6 t/ha	SSNM	200	100	100	43	25	20	10	15
	RDF	150	75	75	-	-	-	-	-
	FP	120	30	30	-	-	-	-	-
Chickpea–SSNM goal of 2.5 t/ha	SSNM	40	75	25	20	5	5	5	5
	RDF	25	50	0	-	-	-	-	-
	FP	20	50	0	-	-	-	-	-

conducted with three treatments comparing yields and economics of SSNM over recommended rates of fertilizers (RDF) and farmers' practice (FP). The trials were located at Siruguppa, Bijapur, and Navalgund Talukas of Karnataka. SSNM nutrient requirements were identified based on soil tests and the treatments were imposed considering set crop yield goals and available soil nutrients (**Table 2**). Economic analyses considered additional cost of inputs and yield in SSNM over RDF and FP. Trials used high yielding rice, wheat, and chickpea varieties... namely BPT-5204, DWR-162, and A-1, respectively. Rice was transplanted while the other two crops were under protective irrigation and recommended cultural practices.

Photo at top left shows rice in SSNM plot. Photo at top right shows wheat with farmers' practice compared to SSNM. Lower photos show chickpea, SSNM at left and farmers' practice at right.

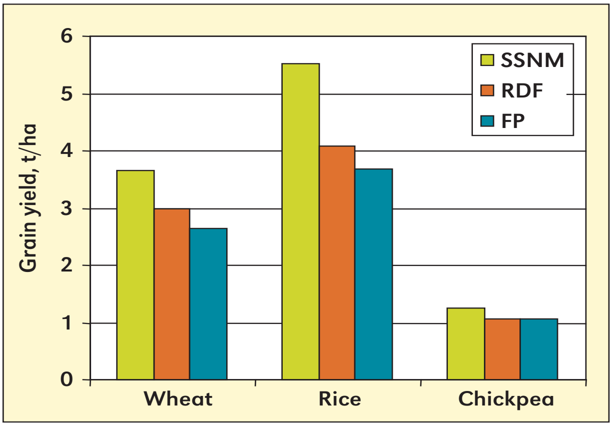


Figure 1. Average yield improvement due to SSNM at five locations.

Nutrient application on the basis of SSNM principles resulted in significantly higher grain yields over FP and RDF in all three crops under investigation. The average rice, wheat, and chickpea grain yields under SSNM, RDF, and FP are shown in **Figure 1**. The yield increases under SSNM show promise for yield improvement in the region.

Wheat yields ranged from 3.5 to 3.8 t/ha under SSNM, 2.8 to 3.2 t/ha under RDF, and 2.6 to 2.7 t/ha in FP. Average wheat yields were 3.66, 2.98, and 2.64 t/ha in the respective practices, signifying 23% higher productivity due to SSNM over RDF and 39% over FP (**Table 3**).

Rice yields ranged from 5 to 6 t/ha (SSNM), 3.7 to 4.5 t/ha (RDF), and 3.4 to 3.9 t/ha (FP), with average yields of 5.5, 4.1, and 3.7 t/ha, respectively. The average yield in-

Table 3. Yield of wheat, rice, and chickpea (t/ha) as influenced by SSNM.

	Wheat			Rice			Chickpea		
Site	SSNM	RDF	FP	SSNM	RDF	FP	SSNM	RDF	FP
1	3.70	3.20 (16)[1]	2.70 (37)[1]	5.70	4.20 (36)	3.70 (54)	1.38	1.14 (21)	1.13 (22)
2	3.80	2.84 (34)	2.60 (46)	5.32	4.00 (33)	3.56 (49)	1.18	1.03 (15)	1.01 (17)
3	3.50	2.96 (18)	2.70 (30)	5.50	4.06 (36)	3.91 (41)	1.22	1.08 (13)	1.08 (13)
4	3.60	3.00 (20)	2.64 (36)	5.00	3.71 (35)	3.36 (49)	1.25	1.06 (18)	1.05 (19)
5	3.72	2.90 (28)	2.56 (45)	6.08	4.50 (35)	3.90 (56)	1.26	1.07 (18)	1.06 (19)
Mean	3.66	2.98 (23)	2.64 (35)	5.52	4.09 (35)	3.69 (50)	1.26	1.08 (17)	1.06 (18)

[1] Numbers in brackets reflect SSNM yield increase (%) over RDF or FP.

crease due to SSNM over RDF was 35% and was 50% over FP (**Table 3**).

Chickpea yields were higher with SSNM compared to RDF and FP, although the yields were not close to the pre-set target of 2.5 t/ha in these trials. The prime reason for these poor yields was moisture stress as a severe drought-like situation prevailed. However, SSNM did increase the average yield by 17 to 18% over official recommendations or FP (**Table 3**), and showed the benefit of balanced fertilization even under low moisture conditions.

Economic Viability of SSNM

Yield increases under SSNM resulted in a vast improvement in the economic feasibility of food crop production. The average additional net income under SSNM in rice, wheat, and chickpea was US$53, 68, and 23 /ha over RDF, and US$115, 101, and 24/ha over FP (**Table 4**). Nutrient input costs resulting from implementation of SSNM will lessen in succeeding seasons as micronutrient applications are likely only required every 2 or 3 years. In such a circumstance, production will be profitable and sustainable in due course of time.

Table 4. Yield increase and economic advantage due to SSNM.

	Additional advantage under SSNM compared to:					
	RDF			FP		
Crop	Yield, t/ha	% yield increase	Net income, US$/ha	Yield, t/ha	% yield increase	Net income, US$/ha
Wheat	0.68	23	53	1.02	39	115
Rice	1.43	35	68	1.83	50	101
Chickpea	0.18	17	23	0.19	18	24

Average of five locations for each crop.

Conclusions

SSNM proved to be advantageous over RDF and FP both in yields and net returns in wheat, rice, and chickpea. These results hold promise as an example showing higher yields could be achieved with balanced use of nutrients as per soil test results and crop requirement. The results suggest that there is opportunity to improve the RDF for these crops. The government's aim is to achieve a second Green Revolution from dryland areas. SSNM is capable of producing hundreds of thousands of additional tonnes of rice, wheat, and chickpea within the region, annually generating billions in additional local currency within the state economy. BC

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Integrating Cash Crop Hedgerows and Balanced Fertilization to Control Soil and Water Losses from Sloping Farmlands

By Shihua Tu, Yibing Chen, Qing Zhu, Yunzhou Guo, Zhonglin Zhu, and Ling Xie

Based on several years of research and demonstrations, adopting cash crop hedgerows and balanced fertilizer technology to combat soil erosion has proven very practical and applicable. It not only reduces soil erosion from sloping farmlands, but also increases crop yield and farmers' income. This integrated new technology has realized the goal of combining social, ecological, and economic benefits, and can thus safeguard sustainable agriculture on sloping lands.

Uplands prevail in the upper reaches of the Yangtze River, making the region prone to severe soil erosion due to a high cropping index, over-grazing, high rates of soil erosion, and a fragile ecology. Annual runoff and silt discharged into the Yangtze River are estimated at 440 billion m^3 and 530 million metric tons (M t), respectively (Yichang Hydrologic Station). Sloping farmlands in the upper reaches account for only 5.5 M ha (16% of total farmland), but contribute 380 M t of soil loss or 44% of total erosion. It is obvious that these regions are the major origin of sediments feeding to the water courses of the Yangtze River. Thus, it is important to seek applicable agronomic measures to prevent soil erosion.

The traditional technology used over the past 20 years in China for soil and water conservation on sloping lands is engineered terracing. Due to its high cost, the technology cannot be adopted by farmers without financial support from government. In order to reduce the cost of soil conservation, a new method of 'cash crop hedgerows' (CCH) was developed and has been tested since the late 1990s in China's southwest provinces of Sichuan, Yunnan, and Guizhou.

Bio-terracing (left) can significantly reduce soil erosion as an alternative to down-slope cultivation (right).

The amount of runoff and soil loss from corn fields with farmers' practice (FP) are closely correlated to intensity and quantity of each rainfall, and both reach peak values in June when the soil surface is not fully covered by the crop canopy and the soils are loose and susceptible to erosion (**Table 1**). After June, though rainfall produces rather large runoff, soil loss is not observed. This is because: 1) with time, topsoil becomes more compact due to root penetration and an increase in soil cohesion; and 2) flourishing crop growth provides full shading that prevents raindrops from directly hitting the soil surface.

Table 1. Results of soil erosion and runoff under farmers' practice (down-slope cultivation) and precipitation in Luodian, Guizhou, 2001.

Month	April	May	June	July	August	September	Total
Rainfall, mm	225	1,569	6,420	444	1,514	308	10,479
Run-off, t/ha	23	661	2,258	36	162	28	3,167
Soil loss, t/ha	0.2	25.8	76.3	nil	nil	nil	102.3

In Yunnan, field experiments were conducted in Xiangyun and Fuming counties, representing two typical erosive soils in the province. Experiments consisted of five treatments including FP (down-slope cultivation), FP + balanced fertilization (BF), FP+BF+Chinese prickly ash tree+Chinese day lily (CCH), contour cropping (CC)+BF and CC+BF+CCH. Amounts of soil lost varied from year to year and were positively correlated to annual rainfall. Any practice that could maximize soil coverage and stabilize topsoil would significantly reduce soil erosion (**Table 2**). On average, FP+BF reduced soil loss by 21%, and this was further reduced by 52% with CCH in the 4-year experiment in Xiangyun County. Compared to FP, soil loss was reduced by 82% under CC+BF and by 88% under CC+BF+CCH. A similar trend was observed at Fuming, but with less overall soil loss.

In Guizhou, field experiments were conducted in Luodian County, including five treatments of FP, FP+BF, wild buckwheat+plum tree (CCH1), Chinese day lily+Chinese prickly ash tree (CCH2), and engineered terracing (ET). Results were similar to those observed in Yunnan, with the reduction of runoff being in the order of CCH1+BF > CCH2+BF > ET+BF > BF > FP, while for erosion the order of reduction was CCH1+BF > ET+BF > CCH2+BF > BF > FP (data not shown). Results illustrate that BF integrated with CCH technology can better maintain sustainable agriculture on these sloping farmlands.

In Sichuan, a number of CCH patterns were selected and tested, including: Chinese toon, loquat tree+day lily, pear tree+day lily, Chinese prickly ash tree, mulberry tree, eulaliopsis (a raw material for paper-making), and honeysuckle. At Jianyang, the best CCH strategy was pear tree+day lily. Similar to Yunnan and Guizhou, this hedgerow pattern has significantly reduced soil loss since 1997. The influence of CCH on soil and water losses was variable, but as amounts of rainfall in-

Table 2. Soil losses (t/ha) in Xiangyun and Fuming counties from May to October (2000 to 2003).

Site	Year	Rainfall, mm	FP	FP+BF	FP+BF+CCH	CC+BF	CC+BF+CCH
Xiangyun	2000	827	5.6	2.3	3.2	1.6	0.9
	2001	1078	42.8	37.4	14.8	6.9	6.5
	2002	959	18.8	11.9	4.8	2.0	1.5
	2003	982	50.2	41.1	9.3	10.6	5.3
	Mean	962	29.4	23.2	8.0	5.3	3.5
	Reduction vs. FP	-	-	-6.2	-21.3	-24.1	-25.8
	Soil loss, %	-	-	-21.1	-72.7	-82.0	-87.9
Fuming	2000	775	12.0	11.9	12.3	0.7	1.0
	2001	879	5.8	3.8	2.3	2.7	0.5
	2002	777	11.7	9.0	8.5	4.2	1.6
	2003	665	2.3	0.8	0.6	0.5	0.2
	Mean	774	8.0	6.4	6.2	2.0	0.8
	Reduction vs. FP	-	-	-1.6	-1.8	-5.9	-7.1
	Soil loss, %	-	-	-20.0	-22.4	-74.3	-89.6

Table 3. Impact of different treatments on crop yield (t/ha) in Yunnan.

Site	Year	FP	FP+BF	FP+BF+CCH	CC+BF	CC+BF+CCH
Xiangyun	2000	6.09	7.04	6.12	7.16	7.06
	2001	6.08	6.32	6.87	6.90	7.02
	2002	6.97	7.18	6.84	7.86	7.53
	2003	5.66	6.14	6.07	6.72	6.90
	Average yield	6.20	6.67	6.47	7.16	7.13
	Yield increase vs. FP (%)	-	7.5	4.4	15.4	15.0
Fuming	2000	4.76	6.01	5.46	10.25	9.84
	2001	3.79	4.48	4.82	4.65	5.14
	2002	7.62	7.73	6.84	8.75	8.63
	2003	5.90	6.44	5.18	6.90	6.78
	Average yield	5.52	6.17	5.58	7.64	7.60
	Yield increase vs. FP (%)	-	11.8	1.1	38.4	37.7

creased the effect of CCH adoption became more pronounced.

All hedgerow crops had an influence on crop yields. The magnitude depended on type and variety. In Yunnan, crop yields under BF alone in both Xiangyun and Fuming were consistently higher than under FP (**Table 3**). Even though CCHs occupied 10% of the field area, crop yields were not negatively impacted. To the contrary, yields were higher than FP – an effect attributed to reduced soil erosion and soil fertility maintenance.

The effect of BF on grain yield trends at Guizhou was similar to that in Yunnan. Although Chinese day lily+Chinese prickly ash tree occupied 17% of the land area, this treatment produced higher corn yields than the FP treatment for 4 years straight (data not shown). Corn yield began to decline from the third year onwards for the CCH treatment using wild buckwheat+plum tree. This influence became more pronounced as plum trees grew larger and is attributed to a larger canopy and a more extensive rooting system for plum which together imposed more shade and competition with corn for soil nutrients.

The effect of CCHs on crop yields in Sichuan was somewhat different from the other two provinces and was possibly due to the two harvests per year at the site. In the first 2 years, pear tree+day lily increased all crop yields, but total annual crop yield started to decline in the third year. A considerable yield reduction was observed on summer corn and sweet potato rather than winter wheat and barley (**Table 4**). This can also be attributed to canopy shading and competition for nutrients from pear tree with summer crops. Since

Table 4. Crop yield (t/ha) response to different treatments in Jianyang, Sichuan (1997 to 2003).

			CCH + CC		CCH+ CC+BF	
Year	Crop	FP (CK)	Yield	vs. CK, ±%	Yield	vs. CK, ±%
1997-2000	Corn	5.1	4.3	-15.8	4.8	-4.6
	Sweet potato	11.4	9.8	-13.8	11.7	+3.1
	Wheat +barley	2.2	2.5	+16.9	3.3	+53.8
	Total yield	18.6	16.6	-10.2	19.9	+6.9
2001	Peanut	3.2	2.7	-16.9	2.8	-15.4
	Wheat +barley	2.4	2.5	4.2	2.5	6.3
	Chinese day lily	-	0.5	-	0.9	-
	Pear tree	-	4.2	-	5.0	-
2002	Peanut	3.2	1.6	-51.6	2.4	-26.3
	Wheat +barley	2.9	2.4	-18.0	2.6	-10.3
	Chinese day lily	-	0.4	-	0.4	-
	Pear tree	-	6.9	-	8.6	-
2003	Peanut	3.1	2.2	-30.5	2.3	-24.5
	Wheat	3.2	2.8	-13.9	3.0	-7.5
	Sweet potato	13.4	10.0	-25.3	11.2	-16.2
	Chinese day lily	-	0.4	-	0.4	-
	Pear tree	-	6.8	-	8.9	-

the trees are in dormancy in winter and bloom in spring, their effect on winter crops is much less significant. In the sixth year, both summer and winter crop yields were more influenced by the CCH as trees grew larger, but BF minimized this influence. For example, yields of three crops under CCH alone were 6% lower than FP, but yields under CCH+BF were 3% higher than FP.

Various crop combinations are being compared in cash crop hedgerows. This demonstration includes plum tree plus buckwheat (*Polygonum cymosum* Trev).

All trials agree that the BF and CCH treatments could increase farmers' income compared to FP. Higher costs were incurred to establish cash crop seedlings and the associated labor was much higher in the first year. CCH treatments began generating higher income streams from the third year onwards. At Jianyang in Sichuan, the CCH and CCH+BF treatments increased net income by US$1,623/ha and US$1,834/ha compared to FP, respectively (**Table 5**). During the 7 years of experimentation, the total increase in net income from CCH and CCH+BF was US$1,731/ha (+29%) and US$3,359/ha (+56%), respectively.

After several years of research, demonstrations, and extension, experts in Sichuan, Yunnan, and Guizhou have worked out several hedgerow patterns and selected a number of crop varieties suitable for local climate, slope gradients, and soils to meet local market needs. Presently, CCH patterns such as pear tree+day lily, Chinese toon, mulberry tree, eulaliopsis, honeysuckle, and Chinese prickly ash tree are used in Sichuan; pear tree+day lily, Chinese prickly ash tree, plum tree+wild buckwheat, and forage crops are used in Guizhou; and Chinese prickly ash tree+day lily, and forage crops are more suitable in Yunnan. Although great progress in CCH research and demonstration has been obtained, further efforts are needed to extend this technology to a larger scale. BC

Table 5. Net income as affected by different treatments in Jianyang, Sichuan.

	Net income, US$/ha		
Year	FP	CCH	CCH+BF
1997	446	-1,665	-1,646
1998	1,144	834	1,052
1999	686	889	1,018
2000	790	1,587	1,771
2001	900	1,625	1,895
2002	1,013	1,719	2,415
2003	998	2,721	2,832
Total net income	5,978	7,709	9,336
Increase vs. FP (%)	-	29	56

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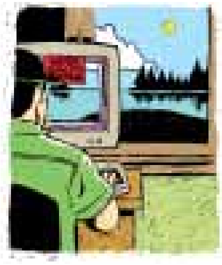
*(Note: Additional information and photos are available at the website: >**www.ppi-ppic.org/ppiweb/swchina.nsf**<.)*

Water Quality In Your Own Backyard—Do You Know What It Is?



Economic challenges continue to loom large for crop advisers and producers involved in nutrient management. Water quality challenges have also increased as we better understand the interactions among land and water and other resources and the effects of specific management activities where we live.

Many have scaled the learning curves associated with soil testing and plant tissue and manure analyses to become more proficient in providing optimum plant nutrition for crops that clothe, shelter, and nourish our society. Fewer of us have invested the time…or found the information in an understandable or "user-friendly" format…to expand our knowledge base and to become more conversant about practical and desirable water quality.

In the U.S., the Environmental Protection Agency (EPA) is usually considered the lead agency…but other federal, state, and some local agencies are also engaged in monitoring and regulating water quality. To protect and improve water resources, these agencies are also charged with the burden to identify certain criteria as guidance in adopting standards. We all would like to see these criteria based on rigorous biological evaluations, assessing cause and effect relationships.

A logical question to ask is: "Do I have any say in the process of developing water quality criteria and standards?" The answer is yes, you can have a voice.

To have a voice in the processes which shape the fate of many involved in the management of our natural resources, each of us can commit to learning more about water quality in the future. We might start by asking the most important question: Do you know the water quality in your own backyard, or your own watershed? That is the starting point in being able to represent your interests.

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