BETTER CROPS

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A Publication of the International Plant Nutrition Institute (IPNI) 2007 Number 1

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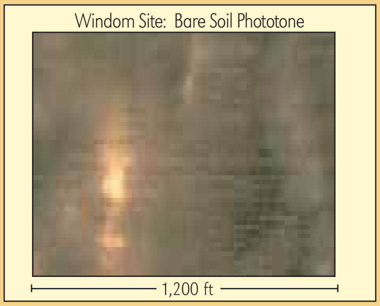

Site-Specific Management of Nitrogen and Phosphorus in a Corn/Soybean Rotation

Rebalancing Nutrient Application in Late-Sown Potato

...and much more

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BETTER CROPS
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Our cover: Images from articles in this issue.
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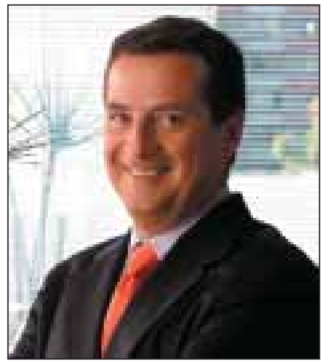
Terry L. Roberts

Notice to Readers: *Better Crops with Plant Food* is now published by the International Plant Nutrition Institute (IPNI). We hope the new format and larger page size will add to the readability and usefulness of the articles. See back cover for more information.

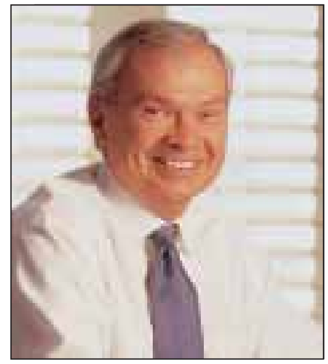
International Plant Nutrition Institute Executive Committee and Officers of the Board Elected

The executive committee and officers of the Board of Directors of the recently established International Plant Nutrition Institute (IPNI) have been named. These responsibilities were determined in the inaugural meeting of the IPNI Board, which took place in Buenos Aires, Argentina, December 3.

Mr. Patricio Contesse, President and Chief Executive Officer (CEO) of SQM, was elected as the first Chairman of the IPNI Board. Mr. Mike Wilson, President and CEO of Agrium Inc., was elected Vice Chairman. Mr. Stephen R. Wilson, Chairman and CEO of CF Industries Holdings, Inc., was named Finance Committee Chair. All three were elected for 2-year terms and will serve as members of the IPNI Executive Committee, which also includes: Mr. Mario Barbosa Neto, CEO of Bunge Fertilizantes S.A.; Mr. Joachim Felker, Member of the Management of K+S KALI GmbH; Mr. James Prokopanko, President and CEO of Mosaic; Mr. Oleg Petrov, General Manager of Uralkali Trading SA; and Dr. Terry L. Roberts, President of IPNI.



Mr. Patricio Contesse



Mr. Mike Wilson

Mr. Contesse has served as Gerente General (Chief Executive Officer) of SQM since 1990. He is a 1975 graduate of the University of Chile, School of Forestry Science. Mr. Contesse has broad experience in the fertilizer, mining, and forest products industries. SQM (Sociedad Quimica y Minera de Chile S.A.) was founded in 1968 to reorganize the Chilean nitrate industry and privatization was completed in 1988. Today, SQM is a worldwide leader in specialty plant nutrition as well as other business areas.

Mr. Bill Doyle, President and CEO of PotashCorp, served as Chairman of the Potash & Phosphate Institute (PPI) Board of Directors from 2004 through 2006. He announced earlier that PPI has committed its scientific staff to the new global IPNI organization, which officially began operations January 1, 2007. Therefore, PPI will no longer exist. IPNI will immediately have effective scientific programs in place in North America, Central and South America, China, India, and Southeast Asia. IPNI anticipates establishing programs in Western and Eastern Europe as well as in the Middle East.

IPNI is composed of fertilizer industry companies that are basic producers of nitrogen (N) and/or phosphate (P) and/or potash (K) and/or sulfur (S) for agricultural use. The purpose is to help provide a coordinated scientific foundation for fertilizer nutrient use and to scientifically address associated environmental issues.

Founding members of IPNI are: Agrium Inc.; Arab Potash Company; Belarusian Potash Company; Bunge Fertilizantes S.A.; CF Industries Holdings, Inc.; Groupe OCP; Intrepid Mining, LLC; K+S KALI GmbH; Mosaic; PotashCorp; Saskferco; Simplot; Sinochem Hong Kong Ltd.; Spur Ventures Inc.; SQM; Terra Industries Inc.; and Uralkali. BC

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- Better Crops, Better Environment...through Science

Phosphorus Absorption and Accumulation in Apple

By Yan'an Tong and Fan Hongzhu

Phosphorus concentration and accumulation in field-grown Fuji apple trees showed that fall accumulated P was used to meet demand during fruit expansion in late July. Fertilizer P should be applied in the fall and just prior to fruit expansion.

Phosphorus fertilization has an important impact on the yield and quality of upland apple production in northwest China. Past study has focused on this relationship, but little information is available on plant uptake, translocation, and distribution of P in apple trees. This article outlines a comprehensive study on the dynamics of P uptake and distribution within Fuji *(M. micromalus. Makino)* apple trees.

A trial was arranged in Qishan County, on the southern portion of the Loess Plateau in Shaanxi, which is well suited to quality apple production and provides a good representation of typical upland apple production in northwestern China. Cultivated apple area in Shaanxi has reached 0.426 M ha, producing 6.0 M t—27% of China's and 10% of the world's apple production.

The orchard site was comprised of 9-year old Fuji apple trees with a row spacing of 2 m and 3 m between trees. The trial was carried out during 2004 and 2005. Samples were taken from three trees at similar stages of development on five dates. Sampling in 2004 took place on March 26 (sprouting and foliage growing period), April 30 (young fruit stage), July 30 (fruit expansion stage), September 21 (fruit maturity), and on January 15, 2005 (tree dormancy). Samples of fruit, foliage, new tops, branches, trunks, and roots were collected each time. Root samples included all those within a 100 cm depth and a radius of 100 cm around the trunk. The cortex and xylem within the trunks and roots were divided and analyzed separately. Enzymatic activity was destroyed by placing plant parts in an oven set at 100 to 105 °C for 15 minutes, and then samples were dried to a constant weight at 70 to 80 °C. Samples were ground

Apple tree sampling.

Demonstration orchard for balanced fertilization.

and digested with concentrated sulfuric acid (H_2SO_4) and hydrogen peroxide (H_2O_2). The P content of the resulting solution was measured colorimetrically.

Results from the study showed a sharp increase in biomass from the early growth period in March to fruit maturity and harvest in September (**Figure 1-A**). Tree growth after this period slowed significantly. Apple trees accumulated an average of 37.1 kg P/ha within the 11-month study period, in which P destined for fruit and foliage amounted to 7.9 kg P/ha. Very little P was removed by trees between March and late July (**Figure 1-B**). This agrees with previous results (Tagliavini et al., 1998) as initial P demand resulting from new leaf and branch growth is apparently translocated from sources stored the previous season. Trees absorbed the majority of P after July 30. The days between July 30 and September 21 represented the peak period of demand for P. Subsequent plant samples collected up to mid-January suggest continued P uptake and accumulation within the primary storage organs (**Figure 1-B, Table 1**).

Abbreviations and notes for this article: P = phosphorus; M ha = million hectares; M t = million metric tons; m/d = month/day

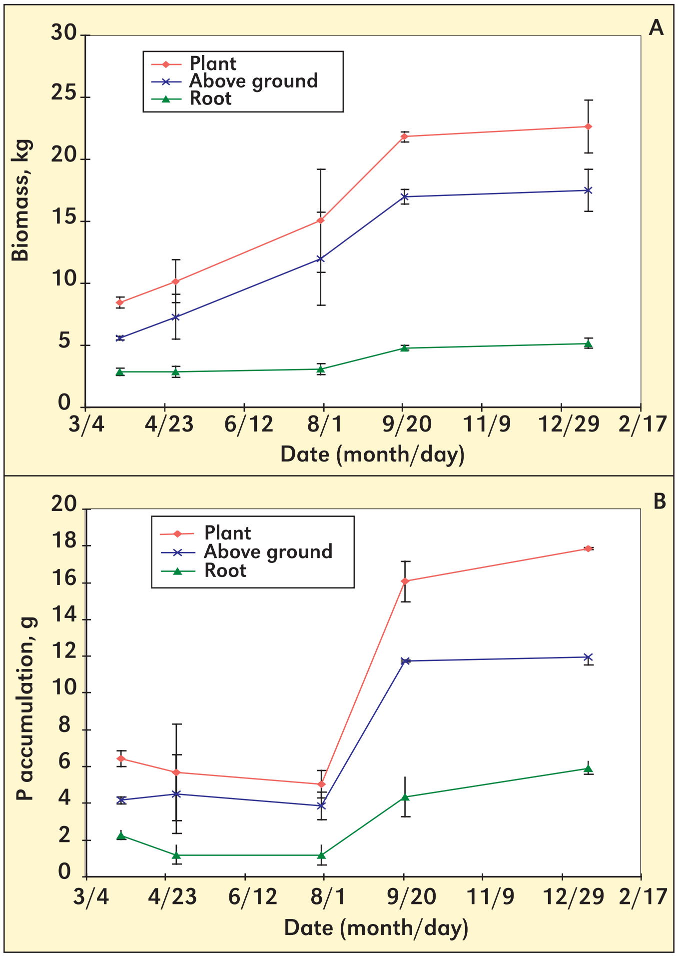

Figure 1. Annual changes of biomass (A) and P accumulation (B) in apple trees.

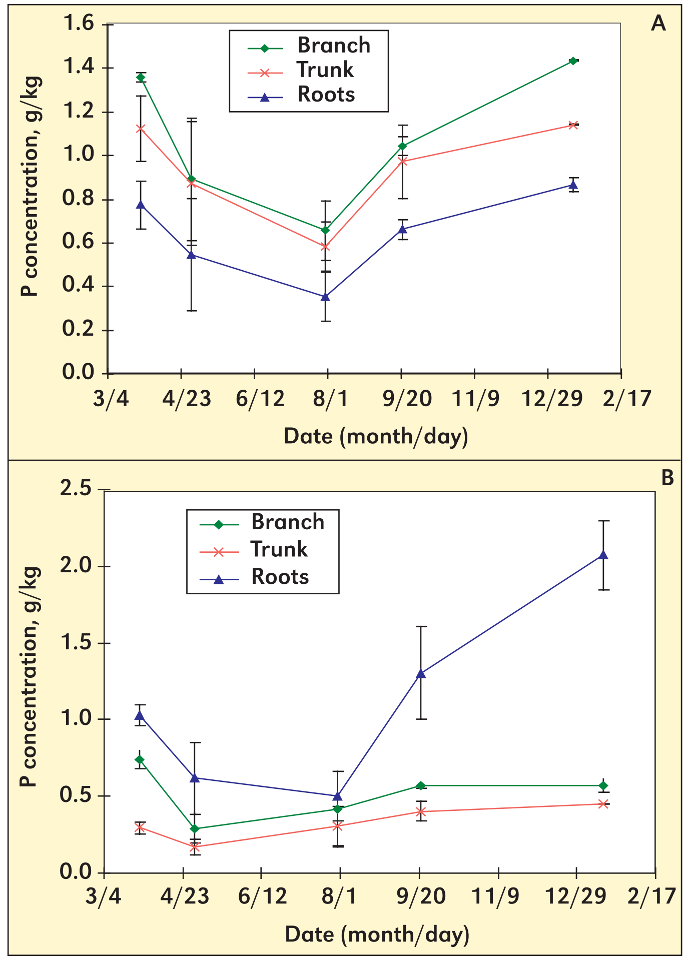

Figure 2. Dynamic changes of P content in organs of cortex (A) and xylem (B)

From July to January, the amount of P accumulated in branches, trunks, and roots increased by 410%, 325%, and 397%, respectively (**Table 1**). Phosphorus accumulation within these storage organs reached a maximum at dormancy in January. At this point, branches, trunks, and roots contained 36%, 22%, and 34% of the total plant P, respectively. This ranking of P accumulation within the primary storage organs agrees with results reported for N storage (Grassi et al., 2003; Frak et al., 2002).

The dynamics of annual P concentrations within collected cortex and xylem are provided in **Figure 2-A and 2-B**. Phosphorus within the cortex of branches, trunks, and roots declined from March to July by 51%, 48%, and 55%, respectively, and reflect the required P redistribution to active growing tissues. Plant P uptake is signaled as cortex P content began to increase in all three organs between the fruit-expanding period in late July and dormancy in January. Tree branches had the highest cortex P during all growing stages, followed by the trunks and roots.

Phosphorus within the xylem of branches, trunks, and roots also decreased during early growth (**Figure 2-B**). Concentrations dropped to their lowest levels in April and then rose after July, especially in roots. In contrast to cortex P measurements, during all growing stages xylem P concentrations were highest within the roots, followed by the branches and then trunks.

Measurements of cortex and xylem P concentrations support the conclusion that apple tree roots take up little P in the spring and early summer. The decrease of P concentrations in the cortex and xylem highlights the early spring and sum-

Table 1. Phosphorus accumulation in apple tree organs at different sampling times.

	Sampling date, m/d				
Organ	3/26	4/30	7/30	9/21	1/15
Fruits, g/tree	–	0.12 ±0.02[c]	0.42 ±0.38[bc]	2.84 ±0.76[abc]	–
Leaves, g/tree	0.24 ±0.03[c]	2.02 ±1.04[a]	1.02 ±0.52[abc]	1.93 ±0.01[bc]	–
Shoots, g/tree	–	0.22 ±0.13[bc]	0.27 ±0.19[c]	0.82 ±0.17[c]	1.39 ±0.40[c]
Branch, g/tree	2.73 ±0.07[a]	1.27 ±0.77[ab]	1.24 ±0.43[a]	3.53 ±0.39[ab]	6.33 ±0.38[a]
Trunk, g/tree	1.19 ±0.19[b]	0.88 ±0.39[bc]	0.92 ±0.41[abc]	2.62 ±1.03[abc]	3.91 ±0.57[b]
Roots, g/tree	2.27 ±0.34[a]	1.19 ±0.50[abc]	1.19 ±0.52[ab]	4.33 ±1.50[a]	5.91 ±0.49[a]
Total plant, g/tree	6.43 ±0.41	5.70 ±2.63	5.06 ±0.75	16.07 ±1.10	17.54 ±0.06
Orchard, kg/ha	10.70 ±0.7	9.50 ±4.4	8.40 ±1.2	26.80 ±1.8	29.20 ±0.1

± represents standard deviation
Numbers within sampling dates followed by the same letter are not different at p = 0.05.

mer transfer of P from storage organs to new spring growth, fruits, and new tops. This further confirms that P requirements of early growth originate from P absorbed and stored in the cortex and xylem during the previous year.

Total annual net P accumulation in this established apple tree orchard with a yield of 48 t/ha amounted to 28.7 kg/ha, in which 18.4 kg/ha was accumulated from July 30 to September 21; 10.3 kg/ha was taken up from September 21 to January 15. Two distinct periods of plant P demand were identified, the first beginning in early August to support fruit expansion, the second in mid-September after fruit harvest to replenish P reserves in all plant storage organs. Initial P demand resulting from new leaf and branch growth depends on sources stored over the previous season.

Although it is difficult to quantify the fertilizer recommendation for apple orchards by soil testing at present, it is recommended to construct and monitor the P balance in order to properly compensate for annual apple harvests and the amount of P removed by fruits and leaves. Considering a P fertilizer use efficiency of 25% (Lou, 1998), the initial recommendation for P application required to offset P removal within the orchard would be 115 kg P/ha without considering P supplied from soil. Results from this study indicate that approximately 69 kg P/ha (60%) should be applied basally in the autumn after fruit harvest and the remaining 46 kg P/ha (40%) should be applied prior to fruit expansion in early July. BC

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Conversion Factors for U.S. System and Metric Units

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

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

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

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

Other Useful Conversion Factors

Phosphorus (P) x 2.29 = P_2O_5 P_2O_5 x 0.437 = P
Potassium (K) x 1.2 = K_2O K_2O x 0.830 = K
parts per million (ppm) x 2 = pounds per acre (lb/A)

Corn (maize) grain — bu/A x 0.0629 = t/ha
Wheat or Soybeans — bu/A x 0.0674 = t/ha

Forest Fertilization and Water Quality in the United States

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

When proper best management practices (BMPs) are employed for forest fertilization, changes in streamwater chemistry are very slight and there have been no detectable effects on the composition or productivity of stream aquatic communities. Short-term increases in peak concentrations of NO_3^-, NH_4^+, HPO_4^{2-}, and $H_2PO_4^-$ in streamwater can occur after forest fertilization. Increases in average concentrations are much lower than the peak values. High concentrations of nutrients in streamwater tend to occur when fertilizers are directly applied to streams, with repeated fertilization, with use of NH_4NO_3 rather than urea as the N source, or with fertilization of "N-saturated" hardwood forests.

Forest fertilization is a widespread silvicultural practice in two regions of the U.S. In the southern states, over 1.2 million acres of pine plantations were fertilized with P or N+P in 2005 (**see photo below**). In the Pacific Northwest, operational fertilization is also a common treatment with about 100,000 acres of forest fertilized annually. The main tree species fertilized in the South are loblolly pine (*Pinus taeda*) and slash pine (*Pinus elliottii*). In the Pacific Northwest, the main species is Douglas fir (*Pseudotsuga menziesii*). In forestry, N is commonly applied as urea or DAP. Phosphorus is applied as either triple superphosphate or DAP. The cumulative growth response of loblolly pine plantations following mid-rotation fertilization with N+P is approximately 450 ft^3/A over 8 years. In Douglas fir stands, volume growth may increase 20 to 30% following N fertilization. Returns from forest fertilization can be financially attractive, sometimes in excess of 15%, depending on factors such as fertilizer cost and the value of the timber produced.

Approximately 80% of the freshwater resources in the U.S. originate from forested watersheds. The quality of water draining forests is typically higher than the quality of water draining areas under any other major land use (**see photo above right**). In the U.S., the concentrations of total N and P in water draining agricultural areas are about 9 times greater than concentrations found in forested streams. The concentration of NO_3-N may average about 0.23 mg N/L for very large forested watersheds in the U.S., compared with 3.2 mg N/L for streams in a number of large agricultural watersheds.

Forest fertilization of a slash pine stand in Florida with a forested buffer strip in the background.

High quality water in a stream flowing from a forested watershed.

Although the overall quality of water draining forest landscapes is very high, some forest practices, such as fertilization, may potentially alter water quality. Over the last 25 years, many studies, including several reviews, have been published. They generally concluded that forest fertilization poses little or no risk to water quality parameters when proper BMPs are implemented.

Streamwater Responses to Forest Fertilization

Fertilizer applications may alter streamwater chemistry across temporal and spatial scales. The transformation and subsequent movement of nutrients supplied in fertilizer determines the potential impact on water quality. Urea fertilization typically leads to immediate increases in urea-N concentrations in soils. Urea hydrolysis is relatively rapid in forest soils—as in agricultural soils—leading to rapid formation of NH_4^+. Ammonium oxidizes to form NO_3^- over periods of weeks to months following fertilization. Ammonium concen-

Abbreviations and notes for this article: NO_3^- = nitrate; NH_4^+ = ammonium; NH_4NO_3 = ammonium nitrate; orthophosphate = HPO_4^{2-} and $H_2PO_4^-$; P = phosphorus; N = nitrogen; DAP = diammonium phosphate; mg/L = milligrams per liter.

trations in soils tend to increase over a period of weeks or months, and NO_3^- concentrations may be increased for a period of a year or more following fertilization. Nitrate is much more mobile in soils and has a greater potential for transport to streams. The P concentration in soils following P fertilization is determined primarily by the rate of fertilizer applied and P adsorption capacity of soils. The P sorption capacity of most forest soils is high and there is generally little movement of P to streams over time from forest soils.

Without fertilization, the concentrations of NO_3-N observed in most forested streams are <1.0 mg/L. Most fertilization studies have shown peak concentrations of NO_3-N <2.0 mg/L following fertilization, but NO_3-N peaks from 10 to 30 mg/L can occur. Some of the highest values observed have been in several studies in the Fernow Experimental Forest in West Virginia. Forests at this site appear to be almost "N saturated", and fertilization led to high NO_3-N concentrations in streamwater, regardless of form of N applied (urea, NH_4NO_3, or ammonium sulfate). However, hardwood forests in this region are almost never operationally fertilized with N.

Ammonium-N concentrations (maximum and annual averages) are usually very low in streams draining unfertilized forests. Fertilization typically has only marginal effects on NH_4^+ concentrations, except when N fertilizer is added as NH_4NO_3. Streamwater standards for NH_4-N are rarely exceeded following fertilization.

Average concentrations of total P are also generally very low in streams draining unfertilized forests, but P fertilization can increase the average P concentration by several fold. Transient peaks in P concentrations are not uncommon following P fertilization. We expect that the transient timing of increases in P concentration, coupled with P removal and dilution downstream, probably result in little overall effect on aquatic ecosystems.

The fertilizer material used and the rate applied to the forest also have an impact on streamwater. Streamwater NO_3^- concentrations tend to be increased more by the application of NH_4NO_3 than by urea. Since NH_4NO_3 is seldom used in forestry, the impact of forest fertilization on stream NO_3^- is likely to be small, particularly when forested buffer strips are used. Nitrate concentrations in streams tend to increase with the number of times fertilizer is applied during a rotation. In a study with 23 fertilized stands, streams in unfertilized stands averaged about 0.3 mg NO_3-N/L, compared with 0.6 mg NO_3-N/L for areas fertilized once, and 1.0 mg/L for areas fertilized two or three times. Although higher rates of fertilizer may affect streamwater NO_3^- concentrations, even relatively high fertilization rates typically do not lead to NO_3^- levels that exceed water quality standards.

Elevated nutrient concentrations in streamwater following fertilization tend to become diluted relatively quickly downstream, as a result of nutrient uptake, transformation into gases, or dilution with additional water. Forest fertilization will typically not degrade water quality relative to drinking water uses, considering that even high peaks of NO_3^- concentration typically last a few days or weeks at most, and that dilution in downstream waters should reduce high NO_3^- concentrations by more than an order of magnitude within several miles of the fertilized site. It is also important to note that unlike with agricultural crops—where fertilizers may be applied several times each year—even in the most intensively managed forests, fertilizers are typically applied only 3 or 4 times during a 20 to 40-year rotation.

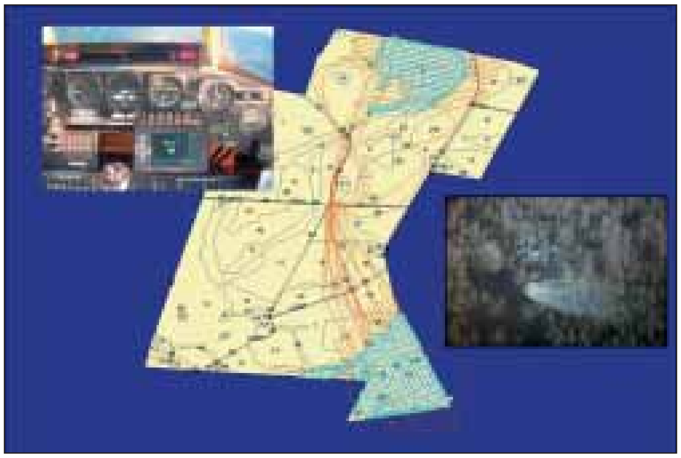
Forested buffer strips are established along intermittent streams in the Coastal Plain of the southern U.S. to protect water quality as a forestry BMP.

Role of Forested Buffer Strips in Maintaining Streamwater Quality

Because the major impacts on water quality occur when fertilizers are applied directly to streams, forestry BMPs recommend that forested buffer strips be established as streamside management zones (SMZs) to protect water quality when forests are fertilized (**see photo above**). The minimum width of the SMZ is generally 30 to 50 ft. In many states, wider SMZs may be required depending on the type and size of the stream, and the adjacent topography. In Virginia, for example, the width of the SMZ ranges from 100 to 200 ft., depending on the slope of the adjacent land, around streams and lakes that serve as municipal water supplies.

A variety of studies have documented the efficacy of forested buffer strips in moderating flows of chemicals from agricultural lands into streams. For example, NO_3^- movement to streams can decrease by more than 80% in agricultural areas where streamside forest buffers are used. Phosphate is also effectively removed by forested buffers. Up to 99% of the P moving from agricultural fields can be removed in forested buffer strips. Much of the P that moves from agricultural fields is adsorbed to soil particles, and forested buffer strips are very effective at trapping sediment and associated P.

Buffer strips can also substantially reduce the urea-N and NH_4-N in streamwater. The effects on NO_3-N concentrations are likely to be smaller. A buffer strip approximately 165 ft. wide (50 m) can reduce concentrations of urea and NH_4^+ by about an order of magni-



Precision application of fertilizer to selected forest stands in the southern U.S. uses satellite navigation.

tude (relative to the treatment without buffer strips), and reduce the concentration of NO_3^- by about 60%. The reduction in urea and NH_4^+ results from less direct input of fertilizer to the streams, and the reduction in NO_3^- probably results from the reduced effects on soil chemistry near the stream. A multi-year study in Florida evaluated the effectiveness of forestry BMPs for protecting aquatic ecosystems during intensive forestry operations, including fertilization. A bioassessment approach showed no significant differences in the aquatic ecosystem between the reference and the treated stream sections following fertilization.

Most of the detrimental effects of forest fertilization on water quality occur when fertilizer is applied directly to the streams. Precision silviculture is now being implemented throughout the U.S. Fertilizer prescriptions are made on a site-specific basis and are customized based on species, stand age, and soil conditions using sophisticated geographic information systems (GIS). The geographic coordinates of stands selected for fertilization are uploaded to satellite Global Positioning System (GPS) navigation equipment located in tractors and aircraft used to apply fertilizer. The GPS technology allows precise application of the fertilizer to the designated stand and enables the applicator to avoid fertilizer application to streams and the adjacent buffer strips (**see illustration above**). In this manner, the appropriate rate of fertilizer is applied only to the designated area which increases the efficiency of the fertilizer treatment and decreases the potential for adverse impact to aquatic systems.

Summary

Several dozen studies from around the world provide insights on the effects of forest fertilization on water quality. Forest fertilization can lead to modest increases in streamwater nutrient concentrations. The greatest increases come from 1) direct application of fertilizer to streams, 2) use of NO_3^- forms of fertilizer, and 3) the application of high rates or repeated doses. Even in these situations, water quality impacts are generally small and transient. No evidence of changes in aquatic ecosystems has been reported from forest fertilization operations. Best management practices that include streamside management zones effectively protect water quality following forest fertilization. Modern precision silvicultural practices help ensure that the fertilizer is applied only to the desired portions of the forest, reducing the impacts on water quality. Because of the inherently higher native productivity and fertility of many agricultural soils, streams draining agricultural lands may have higher native nutrient concentrations compared to streams draining forested lands, whether or not the forests are fertilized. BC

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Rebalancing Nutrient Application in Late-Sown Potato

By B.R. Gupta, T.P. Tiwari, Rakesh Tiwari, and K.N. Tiwari

Common practice for cropping systems in the Gangetic Plain places a heavy reliance on soil nutrient reserves. Nutrient balances for most crops indicate significant depletion, especially for K. Potato provides one such example of a system in need of revitalization.

The majority (80%) of potato production occurs within the most fertile alluvial soil zones spreading from Punjab in the northwest to West Bengal in the northeast. These soils are developed on the alluvium of the Ganges and Yamuna rivers. However, soil fertility in the region has declined due to continuous intensive cropping with inadequate and unbalanced use of nutrients.

The 440,000 ha of potato planted in Uttar Pradesh currently accounts for 33% of India's total potato area and 44% of its total production at 10.2 M t. It is a relatively high-yielding zone within India, with an average productivity of 23 t/ha…one-third higher than the national average. This is below the region's yield potential under balanced fertilization.

At current levels of productivity in Uttar Pradesh, annual N, P_2O_5, and K_2O removal by harvested potato tubers amounts to 60,000, 14,000, and 87,000 t, respectively. This represents 2.5% of the total N, 1.8% of P_2O_5, and 60% of K_2O consumed by all crops in the state. A desired 50% increase in productivity would increase potato's share of nutrient use to 3.8%, 2.7%, and 90%. Total K removal by major crops is much higher at 17 M t K_2O. Thus, farmers of Uttar Pradesh depend heavily on soil K reserves for all crops. Since total K additions through external sources only amount to 142,000 t, the state has a large negative K balance of 15.6 M t K_2O.

It is not surprising that symptoms of K deficiency and other nutrients are easily observed and generally spreading throughout potato fields within the state and country. Average per hectare fertilizer use for potato in Uttar Pradesh is comprised of 91 kg N, 29 kg P_2O_5, and 6 kg K_2O…a use ratio of 15:5:1. The current state department of agriculture fertilizer recommendation of 150-75-75 kg/ha is less commonly adopted, but is also proving to be suboptimal to sustain optimum productivity, produce quality, and farmer profit.

Table 1. Outline of treatments applied to potato, Kanpur.

Treatment	Ratio	N	P_2O_5	K_2O
		kg/ha		
T_1	2:1:2	150	75	150
T_2	2:1.25:2	150	94	150
T_3	2:1.50:2	150	112	150
T_4	2:0:2	150	0	150
T_5	2:1.25:1.5	150	94	112
T_6	2:1.25:1	150	94	75
T_7	2:1.25:0	150	94	0
T_8 (SR)	2:1:1	150	75	75

Potato plants shown at left have clear symptoms of K deficiency.

This field experiment was initiated to compare the effectiveness of selected macronutrient application ratios. The study was located at the Fertilizer Research Station in Pura, Kanpur, during the 2004/05 *rabi* winter season (October to March). The site had a sandy loam soil, pH 8.2, and 0.35% organic carbon. Available N (alkaline permanganate method), P (Olsen), and K (ammonium acetate extractable) were all considered low at 175, 8.5, and 110 kg/ha, respectively. Urea, DAP, and KCl were used as fertilizers supplying eight treatment combinations (**Table 1**). Varying ratios of NPK were formulated and tested based on the need to improve the state recommendation for P and K. Along with treatments omitting P and K, the state recommendation (SR, T_8) was compared against those supplying 25 or 50% more P and 50 or 100% more K. Basal applications of

Tuber yields and net returns were highest with balanced NPK application. Rates of 150-112-150 kg N-P_2O_5-K_2O produced 34% more than the state recommendation.

Abbreviations and notes for this article: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Zn = zinc; DAP = diammonium phosphate; KCl = potassium chloride; M t = million metric tons.

Treatment	Yield, t/ha	Response over SR, %	Net return over SR, Rs/ha	Benefit-to-cost ratio
T_1	30.1	3.2	2,700	5
T_2	33.4	14.6	14,010	16
T_3	39.0	33.5	33,050	38
T_4	23.7	-18.9	-18,630	–
T_5	33.5	14.7	14,470	25
T_6	31.2	7.0	-6,870	23
T_7	23.4	-20.0	-20,220	–
T_8 (SR)	29.2	–	–	–
C.D.[1] 5%	3.4			

Table 2. Effect of treatment on fresh tuber yields and net returns.

[1]C.D. = critical difference
US$1 = Rs. 46.58

S and Zn were provided to all treatments at 40 kg S/ha and 25 kg $ZnSO_4$/ha. Planting of "Kufri Anand" cv. commenced in early December and was grown using all recommended cultural and pest management practices including weed control. Irrigation was provided as needed to avoid moisture stress. Potato tubers were harvested at full maturity in mid-March, 2005. Highest tuber yield of 39.0 t/ha was recorded under T_3 providing 150-112-150 kg N-P_2O_5-K_2O/ha—a ratio of 2:1.5:2 (**Table 2**). SR (T_8) of 150-75-75 produced 29.2 t/ha, 34% less yield. Treatments omitting P (T_4) and K (T_7) provided the lowest yields of 23.7 and 23.4 t/ha, which mirror the state average.

Net returns followed yield responses, with T_3 being most profitable at Rs.33,050/ha (US$700) over the SR, followed by T_5 at Rs.14,470/ha (US$310), and T_2 at Rs.14,020/ha (US$300) over the SR. Omission of P and K proved least economical as net returns from these plots were Rs.18,625 (US$400) and Rs.20,220/ha (US$405) below the SR, respectively. Benefit-to-cost analysis also determined T_3 to be superior at 38—signaling this to be the most economic yield, or most pertinent goal for farmers.

Discussions on improved fertilizer P and K input strategies also extend to issues surrounding nutrient use efficiency. Typically, N use efficiency is of most critical concern due to input costs and the higher risks of environmental loss associated with greater N mobility. Measuring use efficiency of P and K is less critical since that which is not removed by the initial crop more consistently adds to residual soil pools and is largely available to subsequent crops.

Table 3. Effect of K and P on nutrient uptake in potato.

K_2O rate, kg/ha	Nutrient uptake, kg/ha N	P	K
0	128.9	11.8	133.3
75	185.0	19.0	211.1
112	202.3	20.8	251.5
150	194.9	20.7	258.7
150[1]	259.8	28.0	333.0

Based on N and P_2O_5 rates of 150 and 94 kg/ha.
[1]Treatment used N and P_2O_5 rates of 150 and 112 kg/ha.

Table 4. Effect of K and P on N use efficiency[1] in potato.

K_2O, kg/ha	P_2O_5, kg/ha 0	75	94	112
0			156	
75			208	
112			223	
150	158	201	223	260

[1]Expressed as partial factor productivity (PFP) = grain yield per kg N fertilizer.
Nitrogen supplied at 150 kg/ha across treatments.

The lack of nutrient balance between fertilizer N, P, and K leads to poor N use efficiency in potato production. Uptake of N, P, and K by potato was stimulated with increasing rates of fertilizer P and K (**Table 3**). Narrowing the NPK application ratio from 2:1.25:2 (T_2) to 2:1.5:2 (T_3) produced a 33, 35, and 29% increase in N, P, and K uptake, respectively.

Partial factor productivity (PFP) measurements, provided in **Table 4**, describe the crop response in terms of treatment effectiveness in converting fertilizer N into yield. A steady increase in N use efficiency is achieved as P and K rates increase. However, the PFP_N response reaches a plateau, with no advantage observed at the highest K rate (150 kg K_2O/ha), when P application was limited to 94 kg P_2O_5/ha. A large upward shift in PFP_N was achieved when this P limitation was removed by increasing the P rate to 112 kg P_2O_5/ha.

Cooperators in the potato fertilization study with harvest results.

Higher-yielding potato can be obtained, and nutrient use efficiency substantially augmented, by balanced fertilization—achieved here by keeping the recommended N rate constant and increasing the P and K rates by 50% and 100%, respectively. The current state recommendation not only promotes suboptimal yields and returns to farmers in Uttar Pradesh, but also under-utilizes farm investment in fertilizer inputs, especially N. BC

Dr. Gupta is Professor and Head, Dr. T.P. Tiwari is Assistant Agricultural Chemist, and Dr. Rakesh Tiwari is Research Associate, all with C.S. Azad University of Agriculture and Technology, Kanpur. Dr. K.N. Tiwari is Director of the IPNI India Programme.

Site-Specific Management of Nitrogen and Phosphorus in a Corn/Soybean Rotation

By D.M. Lambert, J. Lowenberg-DeBoer, and G.L. Malzer

Varying N and P together provided the greatest opportunities for yield and profit improvement, compared to a uniform nutrient management strategy in a Midwest study.

It is well known that N and P needs vary within a field. Multi-year, on-farm studies examining N and P interactions at a sub-field scale are not widely available.

A study was established in 1996 on a 30-acre farmer's field near Windom, Minnesota, and continued for 5 years (3 years of corn and 2 years of soybeans). The field had been in a corn/soybean rotation for the last 20 years, with no manure applied.

The site was extensively grid sampled in the fall of 1996. Soil organic matter ranged from less than 2% up to 10%. Phosphorus soil tests ranged from very low (less than 5 ppm) to very high (greater than 15 ppm). Soil pH ranged from 6 to 8. The dominant soils were Aquolls and Udolls: 1) a Jeffers clay loam, 2) Clarion-Swanlake clay loams, and 3) Webster-Delft clay loams.

The study examined corn and soybean responses to combinations of N and P rates. Phosphorus was applied at rates of 0, 50, and 100 lb P_2O_5/A in wider strips that ran the length of the field. Within each of these strips, five rates of N (0, 60, 100, 140, and 180 lb N/A) were applied in narrower strips. Both N and P were applied in the fall prior to the corn growing season. Treatments were replicated three times. During harvest, the plot combine was stopped every 50 ft. and the position of the harvester georeferenced. The combine was equipped with a ground distance monitor and a computerized weigh cell.

Partial budgets examined crop responses to N and P rate combinations. Profitability was evaluated for three scenarios: 1) variable N and P, 2) variable N, but uniform P, and 3) uniform N and variable P. When a variable nutrient rate was examined, profitability was based on the economically optimum rate for a particular area in the field. Consequently, the economics of variable nutrient applications are a "best case" scenario and assume that the optimum rate could have been selected before application. Profitability of uniform rates was determined using currently recommended university Extension nutrient rates and back calculating the predicted yield response.

This bare soil image of the experimental site in Minnesota shows variability of soils over a 1,200 ft. distance.

Average market prices (1997 through 2001) were used for corn and soybean in Cottonwood County, Minnesota ($2.00/bu corn and $4.76/bu soybean). Nutrient costs were $0.17/lb for N and $0.26/lb for P_2O_5. Variable and uniform nutrient applications were $5.35 and $4.00/A, respectively. Map-making and creation of management zones was assessed at $2.96/map. Intensive soil sampling and analysis costs were assumed to be $5.50/A. These costs were reduced to $0.33/A for uniform nutrient management, assuming one composite sample was taken from the field. Costs of mapping, soil sampling, and soil testing were charged in the 1997 year only and assumed to have value for 4 years.

Two years (1997 and 2001) had exceptionally adverse early season weather conditions (**Table 1**). In 1997, late spring snowfall and cold, wet conditions just before planting caused relatively low yields in parts of the field. In 2001, the early part of the growing season was again very wet, causing many zero or near zero yields where drainage was poor.

Corn response to N and P and soybean response to P varied spatially and temporally. Response patterns for N were less stable over time than for P. Economically optimum N rates were generally higher than

Table 1. Yields of N and P management strategies.

			Yield as a percent of the yield of uniform N and P rates		
Year	Crop	Yield of uniform N and P rates, bu/A	Variable N and P	Variable P, uniform N	Uniform P, variable N
			------------- % -------------		
1997	Corn	127	104	100	97
1998	Soybean	44	102	102	100
1999	Corn	152	105	101	104
2000	Soybean	41	102	102	100
2001	Corn	117	107	101	101

Abbreviations and notes for this article: N = nitrogen; P = phosphorus; ppm = parts per million, A = acre.

Year	Crop	Cash flow of uniform N and P rates, $/A	Variable N and P	Variable P, uniform N	Uniform P, variable N
			Increase or decrease in cash flow, compared to cash flow of uniform N and P rates ------------ $/A ------------		
1997	Corn	174.89	-5.09	-8.82	-9.85
1998	Soybean	182.90	4.00	3.90	0.00
1999	Corn	187.94	3.34	0.60	2.70
2000	Soybean	147.30	3.28	2.71	0.00
2001	Corn	117.00	5.96	1.70	-0.87
Net present value:		810.03	11.49	0.10	-8.02

Table 2. Cash flow and net present value of N and P management strategies.

university-recommended whole-field rates. On average, university recommended P rates were close to the economically optimum P rates for this field, ignoring any residual value at the end of the study.

Corn and soybean yields from a variable N and P program, assuming optimum rates could be applied in each area of the field, exceeded those of a uniform rate program in all years of the study (**Table 1**). Varying only one nutrient, rather than both, decreased the opportunities for yield improvements.

Net present value (cash flow minus initial investments) for the variable N and P program exceeded that of a uniform N and P program by approximately $11.50/A (**Table 2**), a significant increase. Uniform N applications combined with variable P rates did not produce significantly higher profit margins.

Returns to a variable N/uniform P strategy were significantly less than the completely uniform approach, indicating that spatial management of N over multiple growing seasons was more difficult than spatial management of P in this field. BC

IPNI/FAR Project # MN-15F

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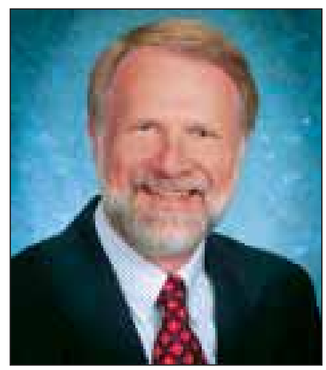
For further reading

Lambert, D.M., J. Lowenberg-DeBoer, and G.L. Malzer. 2006. Agron. J. 98:43-54.

Dr. Paul E. Fixen Elected Fellow of AAAS



The American Association for the Advancement of Science (AAAS) recently awarded the distinction of Fellow to **Dr. Paul E. Fixen**, IPNI Senior Vice President, Americas Group Coordinator, and Director of Research. In making the announcement, AAAS explained that individuals are elevated to this rank because of their efforts toward advancing science applications that are deemed scientifically or socially distinguished. New Fellows will be presented with an official certificate and rosette pin at a forum during February in San Francisco.

Dr. Fixen was elected under the AAAS Section on Agriculture, Food, and Renewable Resources: For outstanding contributions to the science of crop nutrient management, particularly for chloride nutrition and for use of advanced technologies in improving nutrient use effectiveness. AAAS, founded in 1848, is the world's largest general scientific society and publisher of the journal *Science*. BC

International Plant Nutrition Institute Announces the "IPNI Science Award"

IPNI President Dr. Terry L. Roberts recently announced a new program to recognize outstanding achievement in the field of plant nutrition.

"The IPNI Science Award is to be presented each year to one agronomic scientist. Private or public sector agronomists, crop scientists, and soil scientists from all countries are eligible for nomination," Dr. Roberts explained.

The recipient will receive a plaque and a monetary award of US$5,000 (five-thousand dollars). The award recognizes outstanding achievements in research, extension, or education which focus on efficient and effective management of plant nutrients and their positive interaction in fully integrated crop production that enhance yield potential. The purpose of the award is to acknowledge and promote distinguished contributions by scientists involved with ecological crop intensification where productivity is increased and the environment is improved.

For 2007, nominations for the IPNI Science Award must be received by September 30; winner of the award will be announced December 31. To learn more about this program and to obtain a nomination form, visit the IPNI website at >**www.ipni.net/awards**<. BC

Agronomic Education and Credit for Purchasing Fertilizer Bring Environmental and Social Benefits for Coffee Growers

By Reiles Zapata and José Espinosa

Depletion of soil fertility leads to loss of productivity and erosion of the economic capacity to purchase fertilizer required for restoration. Such was the case for farm families in Peru relying on coffee production as their major income. An innovative program developed by an important coffee-exporting company overcame credit barriers for purchasing fertilizer. IPNI assisted by providing agronomic education on best management practices for high yields. The result was improved coffee yields and quality, increased family income, and numerous social and environmental benefits.

Between 1940 and 1950, many small farmers migrated from the highlands of Peru to the northeastern Amazon piedmont to cultivate coffee as a means to improve their standard of living. The activity resulted in small farms located over moderately fertile soils on steep slopes. These families have earned a living from coffee production for many years. Second and third generations of these families found a way of exporting the coffee produced by local farmers through small companies. Comercio & Cia, an example of such an enterprise, has been very successful in marketing Peruvian coffee in the United States and Europe. Beginning in 1994, the company experienced significant growth and now has an important share of coffee exports from Peru. Being part of the coffee production system in its area of influence, Comercio & Cia witnessed the constant decline of yields in its own fields and in the fields of local producers.

Social and Environmental Effects

Low yields were the common denominator of this coffee production area of Peru. It was observed that one of the main limiting factors was nutrient depletion from the fields which were fertilized only with plant and animal residues. Very limited mineral fertilizer was used in coffee production in the area. Constant yield decline drove yields to less than 10 qq of parchment coffee per hectare. On top of low yields and poor income, secondary effects of soil mining were evident.

Effect of soil nutrition depletion on coffee growth and yield.

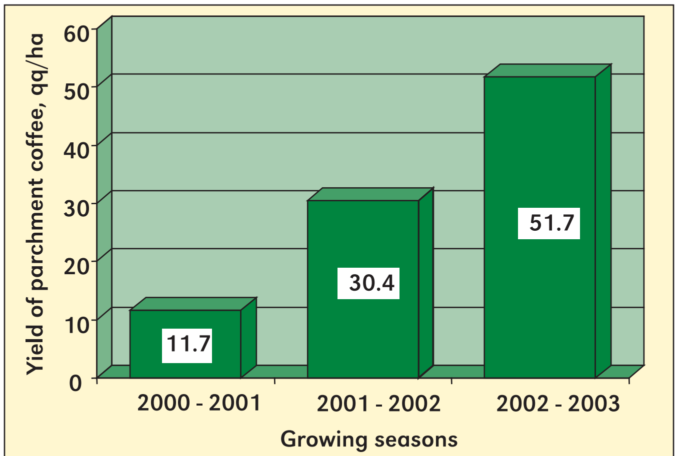
Low income did not allow savings and consequently producers could not invest in farm improvement. This condition reduced family stability and increased the problems associated with poverty. This vicious cycle continued until growers were forced to abandon farms in search for new land to start the cycle again. Soil degradation was evident due to the negative nutrient balance. Biomass production was low and soil cover was poor, exposing the soil to active erosion **(see photo below left)**. The social conditions of the farmers were deteriorating along with the environment. The system was not sustainable and a radical change was necessary.

Agronomic and Social Assessment of Yield Recuperation

In 1997, Comercio & Cia started to evaluate the possibility of improving coffee yields through agronomic management of the crop. A group of technicians…with knowledge of the agronomic, economic, and social conditions of the producers…was assembled. It was evident that the basic agronomic limiting factor was the progressive soil depletion due to the continuous coffee production without replenishing the nutrients exported with the harvested coffee beans. The residues produced on the farms (pruning material, residues from fruit processing, and animal manures) were not sufficient to maintain high, profitable yields. It was essential to replenish soil nutrients with the use of fertilizers and to maintain the crop through good management practices such as trimming and adequate shade management. Field studies like the one presented in **Figure 1** demonstrated the significant effect of fertilizer application on coffee yield.

The fertilizer rate used in this experiment came from well known uptake data in the literature and nutrient uptake studies conducted by the project (data not shown). Based on this information, the project yield goal was set for 40 to 60 qq of parchment coffee per hectare. This is a realistic yield goal for coffee grown under 30 to 50% controlled shade, a situation which is prevalent for the coffee growing conditions of the area. The experiment presented in **Figure 1** was designed to test

Abbreviations and notes for this article: ha = hectares; qq = quintals (in the context of this article, quintal = 100 lb or 45 kg).



Fertilizer blend applied = 20–7–20 N-P_2O_5-K_2O + 3MgO + 4S + Zn + B
Amount applied = 100 g/plant/application; average density: 3,000 plants/ha
Time of application = First application at the beginning of the rainy season, second application in the middle of the rainy season.

Figure 1. Effect of fertilizer application on the yield of parchment coffee at Loma Santa, Jaén, Peru.

Low coffee production with poor crop management and without fertilizer application (left), in contrast with the abundant production in fields with good crop management and fertilizer application (right).

the effect of this defined nutrient rate on coffee yield over a 3-year period. Knowing that the soils were depleted of nutrients, it was expected that the response would be evident in the second and third year. It was important to demonstrate a yield response to fertilizer application, but it was more important to demonstrate the yield potential after the plant stands regain the supporting biomass which is lost as a result of constant nutrient depletion. Timing and form of fertilizer application were also studied. IPNI was actively involved in the basic agronomic training of the technicians of the project and collaborated in the field research as advisor and provider of information.

It was demonstrated that coffee yield and quality were dependent on the nutrient and crop management fitted for the area. However, external factors made the situation even more dramatic. International coffee prices fell in 1999 and coffee producers of the world had to face the worse price crisis in 100 years. The fall of international prices translated into reduction of local prices and Peruvian producers found themselves in an even worse situation. Under these conditions, yield level was more important than ever. Farmers had witnessed the effect of good agronomic management on production and there was interest to improve coffee fields (**see photo above**). Several farmers declared their fields organic with the hope of obtaining a better income with the price difference of the organic coffee in front of the conventionally grown coffee. Nevertheless, low yields made this type of production also unprofitable despite the price incentive.

The research conducted in the area of the project had been able to demonstrate that the solution to the declining yields of coffee was relatively simple from the agronomic standpoint. Making inputs, mainly fertilizers, available to the farmers was the key thing needed to increase and make coffee production profitable in the area. However, the project was also able to determine that the social condition prevalent in the area was perhaps the main limiting factor of coffee production. Poverty derived from low yielding fields did not allow farmers to invest in fertilizers. Government intervention in the area was minimal and private banks did not provide credit to small farmers due to the high risk involved and the lack of legal ownership documentation of the farms which could serve as collateral. It was clear that improving coffee production in the area was more than agronomy.

The Family Program

Comercio & Cia decided to initiate an ample project with small farmers to achieve the proven possible yield increments. The need was evident for designing a project to help farmers organize and legalize their land, to make credit for fertilizer available, to train farmers in the agronomic management of the crop, and to organize the chain of production so harvested coffee could be sold in a secure way and at a fair price.

The Family Program was then born under the slogan: "**More and better coffee to strengthen the family in harmony with the environment.**"

One of the most important factors of the project was to make credit available to the families who join the program. This credit was provided without interest for 3 consecutive years to the farmers who joined the program the first year. The time frame was based on the expected yield response of stressed coffee fields growing in nutrient depleted soils. The collateral was the production which was to be sold to the company at standard price.

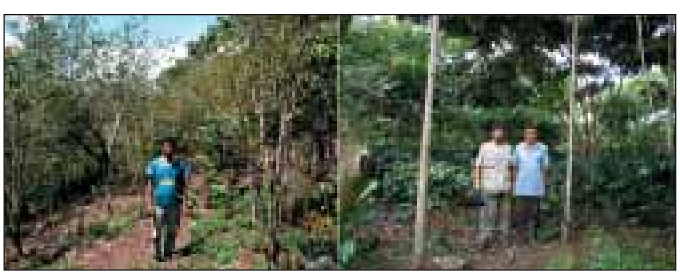
The objective of the Family Program is to recuperate soil fertility to increase coffee production and to improve family income through balanced fertilization, best crop management practices, generation and efficient use of farm residues (leaves and trimmed branches, pulp from fruit processing and animal manures), rational use of natural resources (soil, water, forest), and reforestation. The Family Program officially initiated activities during the 2003-2004 coffee growing season with producers who summed a total area of 950 ha of land under coffee. The farmers did not commit all land

Development of the Family Program: a) community organization; b) training; c) fertilizer availability; d) fertilizing coffee; e) effect on plant growth; f) plentiful production.

under coffee to the program and requested credit to fertilize only part of the coffee fields. The program effectively covered a total of 450 ha. After all, this was a new project and much was heard about the allegedly negative effect of fertilizer use by many different organizations of the region. For this reason, the use of fertilizers by a small group of farmers generated much discussion and controversy. The opponents indicated, among other things, that the use of fertilizers would only degrade the soil more. Obviously, this did not happen and the families in the program enjoyed high coffee yields. Observing the benefits of the fertilizer and crop management on yield, the farmers committed all their coffee fields to the program and new requests to join the program were received. The program expanded rapidly and 7,500 ha of coffee production belonging to 2,500 households were committed for the 2005-2006 cycle.

Benefits of the Family Program

This totally private program evolved to comply with the social responsibility of the community which observed and supported the initiation and development of Comercio & Cia. The program has exceeded initial expectations. International coffee price has reached acceptable levels and this has made the program more valuable. Farmers obtain excellent yields and receive good prices. The effect of the program in the community has been evident and the program will continue expanding to other coffee growing areas of the Peruvian northeast. The tangible effects of the program are economic, social, and environmental. The economic benefits can be summarized in the following aspects: higher production of coffee with better bean quality and cup quality, resulting in higher income which improves the profitability of the households and promotes savings and investment **(Table 1)**.



The Family Program has a favorable effect on the environment. Nutrient depletion eliminates soil cover and degrades the environment (left). Crop and shade management and fertilizer use promote growth, accumulate residues, and improve soil fertility and biodiversity (right).

Table 1. Average yields and prices of coffee during 2006 in the northeast coffee producing area of Peru.

Type	Average yield, qq/ha	Average price, US$/qq
Family Program	30	80
Organic	10	87

The social benefits are the strengthening of the economic and affective unity of the family, implementation of basic sanitation and better schooling driven by better household income, and reduction of emigration to other fragile zones to produce coffee or emigration to enlarge poverty belts around cities. Finally, the environmental effect of the program is undisputed. The vigorous growth of the coffee plants not only produces more fruit yield, but it also produces abundant biomass which is left in the field for recycling after trimming. Higher yields also result in higher amounts of pulp from the processing of the fruit which also comes back to the field for recycling. All of this increases soil organic matter and promotes the recuperation of soil fertility. The abundant cover with leaf litter and trimmed branches protects the soil against erosion. The nutrients applied to the soil also feed the shading trees of the coffee fields. Shade grows vigorously, creating a good habitat which promotes biodiversity. An important effect of the program on the environment is that people can make a living on the farm, reducing the deforestation of new sites to produce coffee (**see photos below left**).

Conclusion

The Family Program has demonstrated that a complete program of rural development can lead to effective crop management that increases coffee yields in socially marginal areas lacking governmental and private attention. The current good international coffee prices make production very profitable. However, if prices were to go down again due to shifting international conditions, the only way to attenuate the situation would be through efficient crop management which can maintain high yields. BC

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Phosphate Efficiency for Corn Following Brachiaria Grass Pasture in the Cerrado Region

By Á.V. Resende, A.E. Furtini Neto, V.M.C. Alves, N. Curi, J.A. Muniz, V. Faquin, and D.I. Kinpara

Efficient use of phosphate fertilizers is still a challenge for long-term soil management in the Cerrado region. Corn yields were quite similar in response to different P sources and application methods following Brachiaria grass pasture. There are indications of very different behaviors between first crop and long-term cultivated soils.

Large-scale production of corn and other grains in the Brazilian Cerrado became viable only after the development of technologies to improve the fertility of soils. The requirement of large amounts of phosphates to correct the fertility of these soils justifies studies to optimize fertilization efficiency.

Taking into account the yield accumulated in sequential cultivations, the performance of some rock phosphates (especially the reactive ones) may be comparable to more soluble fertilizers. It happens due to the conversion of the P from soluble sources into less labile forms while the rock phosphates release the nutrient gradually through time (Novais and Smyth, 1999). In Brazil, long-term field experiments are scarce.

The present work compared the agronomic and economic efficiency of P fertilizers and application methods in a clayey dystrophic Red Argisol (Ultisol), considering the cumulative yield of three successive corn crops. The study was carried out in a field formerly cropped and fertilized, which remained covered by a pasture of brachiaria-grass (*Brachiaria brizantha*) for 10 years before the experiment began. The soil had low P availability, determined by Mehlich 1 (2.0 mg/dm^3) and ion exchange resin (7.8 mg/dm^3) tests.

Treatments were arranged in a 4x3+1 factorial scheme, comparing four commercial P sources (**Table 1**) at the rate of 180 kg P_2O_5/ha: triple superphosphate (TS), Yoorin magnesium thermophosphate (MT), Arad reactive rock phosphate (RP), and Araxá rock phosphate (AP). The study compared three P fertilization methods, including: 1) A single pre-plant broadcast of 180 kg P_2O_5/ha. 2) A single band of 180 kg P_2O_5/ha within the sowing furrow. In each crop, corn rows were located exactly on the original location (relative to the first year band) in the plots. Sowing furrows were manually opened. Thus, there was a constant distance between seed rows and band placement. 3) Three annual bands of 60 kg P_2O_5/ha within the sowing furrow. A check plot without P was also included in the study. In the broadcast application, the P sources were manually distributed and incorporated at 10 cm depth. The soil was limed to obtain a water pH value around 5.5. Soil tillage was done only in the first year. Other nutrients were provided for each crop as starter and sidedress fertilizations for yield expectations of 8 t/ha.

The residual effect from past fertilization, the characteristics of previous crop species, and the genotypic P use efficiency may level the corn response to different P fertilization strategies. Long-term results are crucial to assess the agronomic and economic efficiency of phosphates with distinct solubility.

Grain yield and P exportation at harvest were evaluated. After the third harvest, the soil was sampled (0 to 20 cm depth) to determine residual available P extracted with ion exchange resin. Soil cores were taken at aligned points crossing the sowing row (band place). The plot sample was formed from 10 soil cores (single samples) taken at increasing distances from each side of the row (two of them were taken exactly on the furrow location). This procedure was assumed to represent the average P availability of the plot both in broadcast and

Table 1. Chemical and physical characteristics of phosphate fertilizers and cost per ton.

Fertilizer	Total P_2O_5	Soluble P_2O_5	CaO	MgO	SiO_2	$CaCO_3$ equivalent[3]	Texture	Cost, US$/t
	---	---	%	---	---	---		
TS	46.1	38.3[1]	13.0	–	–	–	Granulated	334.44
MT	18.1	17.6[2]	20.0	7.0	25.0	50	Powder	187.69
RP	33.0	10.0[2]	37.0	–	–	–	Coarse	182.58
AP	22.7	4.3[2]	40.0	–	–	–	Powder	64.84

[1]Water soluble P_2O_5. [2]Citric acid soluble P_2O_5. [3]Alkalinizing effect given in kg $CaCO_3$ for each 100 kg of fertilizer.

Abbreviations and notes for this article:
P = phosphorus;
mg/dm^3 = parts per million;
cm = centimeters;
t/ha = metric tons per hectare;
kg = kilograms

band treatments. The agronomic efficiency index was determined by deducting the check yield and considering TS as a reference for each application method (efficiency = 100%). The economic efficiency of the different fertilization strategies was evaluated by benefit/cost ratio according to the respective yield responses obtained. Calculation was made according to the yield increment of each P treatment relative to check treatment, the cost of P fertilizers, and corn price, regardless of cost differences due to application methods. Other cropping-related costs were assumed as constant.

Using a corn price of US$106.99/t, the benefit/cost ratio was determined as:

(YI x CP) / FP, where:
YI = yield increment, t/ha
CP = corn price, US$/t
FP = fertilizer price, US$/ha (**Table 1**)

Grain Yield and P Exportation

Yield differences were not observed for one-time, first-year broadcast or band applications. When the band application was annually split, AP produced lower yields compared to RP, but neither of them was different from TS or MT (**Table 2**). Apparently, RP solubilization and plant availability was not compromised under the annual band application strategy. The lower yield obtained with AP suggests that it is less suited to a band application at lower rates. Indeed, the yield obtained with AP was similar in all application methods. The low solubility of the product is the biggest restriction to its use efficiency, regardless of the method of application.

The yield responses in this study were not as large as those obtained in earlier P fertilization studies established on previously uncropped Cerrado soils. Usually, yields from check treatments are extremely low (Sousa and Lobato, 2004). Despite anticipated contrasts in P supply between treatments, the cumulative effects of the various P sources tended to equalize after the study's three harvests (**Table 2**).

Table 2. Corn yield and P exportation according to P sources and application methods (total of three crops).

	Application method		
P source	Broadcast	Band	Annually split band
	Grain yield, t/ha		
TS	18.0 a A	18.4 a A	17.8 ab A
MT	18.1 a A	19.2 a A	17.6 ab A
RP	16.5 a B	17.9 a AB	19.4 a A
AP	16.9 a A	17.2 a A	15.8 b A
Check		12.5 **	
	P exportation, kg/ha		
TS	79.6 a A	73.5 ab A	79.3 a A
MT	83.3 a A	86.2 a A	73.9 a A
RP	76.5 ab AB	64.8 b B	81.5 a A
AP	63.7 b A	65.0 b A	67.5 a A
Check		44.4 **	

Averages followed by same small letters in columns or capital letters in rows do not differ through the Tukey test ($p<0,05$).
**Average of the check treatment (-P) differs in relation to the average of the factorial (+P) through the F Test ($p<0.01$).

Residual P fertility resulting from past P application would be a strong candidate for masking the treatment effects at this site. The check treatment produced a considerable yield, which would only be possible given access to a significant source of available P—a condition not detected by Mehlich 1 or ion exchange resin extractants (Resende et al., 2006). This scenario has been associated with the influence of brachiaria-grass, a plant considered quite efficient in P uptake (Sousa and Lobato, 2004). Despite low soil test P levels, a significant amount of P could be present within brachiaria residues, providing a readily bioavailable source capable of supporting the unexpected yields achieved in the check plots.

Generally, when the total P rate was entirely broadcast or banded in the first year, the most soluble TS and MT sources provided for higher P removal by corn. Since the yields obtained with these two application methods were not significantly different among the four P sources, one may suppose that conditions of luxury consumption (excess supply) were created in the case of these highly soluble sources.

Considering the average of all application methods, the use of TS, MT, RP, and AP corresponded to the recovery of 49, 54, 46, and 33% of the applied P, respectively (Resende et al., 2006). These recovery values are not low, given the remarkable P-fixing character of soils from the Cerrado region. Sousa and Lobato (2004) reported that a clayey Latosol (Oxisol) receiving 100 to 800 kg P_2O_5/ha as single superphosphate had average P recoveries after 17 years of cultivation of 36 and 61%, respectively, under an exclusive grain crop system versus a system with *Brachiaria humidicola* during 9 of the 17 years. Such information reinforces the influence of Brachiaria on enhancing soil P availability as well as the dependence of this study's corn responses on its field cropping history.

Agronomic and Economic Efficiency, and Residual Effect of Treatments

The agronomic efficiency index (**Table 3**) indicates that the least soluble AP and RP sources are very distinct products in relation to their P supplying potential. If broadcast, both sources showed similar behavior. If banded, RP was shown to be more plant available. The annual band application of RP produced a significant corn response, but the same was not observed for AP. The more soluble TS and MT sources showed similar use efficiency, and were less influenced by the application method.

The annual band application resulted in higher residual P availability with all sources except AP. For the three most soluble sources, this parceled fertilization method appears to prevent both P luxury consumption by corn and P fixation by soil. The method also provided higher residual effects along with good grain yields, a result of an intermediate P release rate, which did not compromise P uptake by corn. According to Rajan et al. (1996), reactive rock phosphates are the

Table 3. Agronomic efficiency and soil residual available P of sources and application methods of P in corn (after three crops).

P source	Broadcast	Band	Annually split band
	Agronomic efficiency[1], %		
TS	100 a A	100 a A	100 ab A
MT	104 a A	114 a A	98 ab A
RP	74 a B	94 a B	133 a A
AP	79 a A	79 a A	62 b A
	Residual available P[2], mg/dm^3		
TS	10.0 a B	10.2 a B	17.1 b A
MT	9.7 a B	10.5 a B	16.3 bc A
RP	12.1 a B	13.2 a B	24.9 a A
AP	9.8 a A	11.1 a A	12.0 c A
Check		8.7 **	

[1]Treatment with triple superphosphate as reference (in each application method, efficiency = 100%).
[2]Extracted with ion exchange resin.
Averages followed by same small letters in columns or capital letters in rows do not differ through the Tukey test (p<0,05).
**Average of the check treatment (-P) differs in relation to the average of the factorial (+P) through the F Test (p<0.01).

ideal sources for long-term soil management, if they can achieve a controlled P release. In the present study conditions, the advantage of adopting the annual band application method in order to optimize soil fertility is clear. Annual application of 60 kg P_2O_5/ha was sufficient to assure yield gains, replace P removed in harvested grain, and improve fertility for following crops by providing a P surplus.

It is also important to realize that the most suitable treatments in agronomic terms (**Tables 2 and 3**) do not necessarily correspond to those economically more viable (**Table 4**). Longer-term economic evaluation should be made since the P treatments appeared to have distinct residual soil effects at the end of 3 years. The evaluation of yield accumulated from a number of successive crops, field history, and corn genotypic P efficiency have minimized differences between treatments, favoring those with lower P supply potential. Thus, RP and AP, the less soluble but lower cost P sources, provide better cost/benefit ratios. Results showed similar efficiency of different P sources and application methods for corn following Brachiaria grass pasture. Probably, the Brachiaria strongly influences the soil P dynamics in the formerly-fertilized soil, converting residual P into organic, readily-available forms enough to attend a significant part of the corn demand. BC

Table 4. Benefit /cost ratio of sources and application methods of P in corn (total of three crops).

P source	Broadcast	Band	Annually split band	Average
TS	4.5	4.8	4.3	4.5
MT	3.2	3.8	2.9	3.3
RP	4.2	5.8	7.4	5.8
AP	9.1	9.7	6.9	8.6
Average	5.3	6.0	5.4	5.6

Dr. Resende (e-mail: alvaro@cpac.embrapa.br), Dr. Alves, and Dr. Kinpara are researchers of the Brazilian Agricultural Research Corporation (Embrapa Cerrados and Embrapa Milho e Sorgo, Brazil). Dr. Furtini Neto, Dr. Curi, Dr. Muniz, and Dr. Faquin are professors at the Federal University of Lavras (Brazil).

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Phosphorus Management in a Dry-Seeded, Delayed-Flood Rice Production System

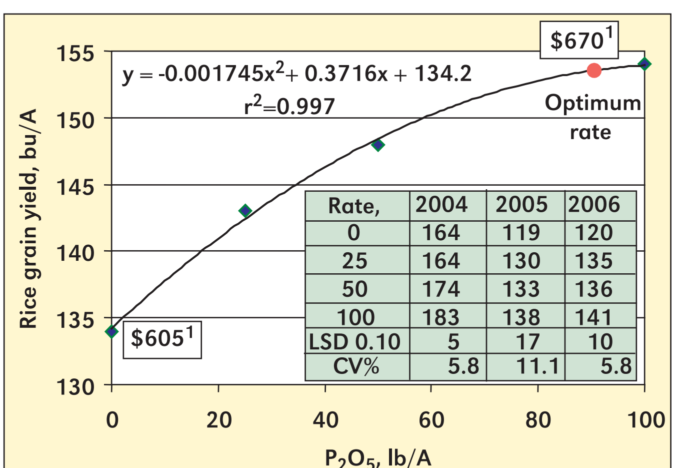
By David Dunn and Gene Stevens

"Hidden hunger" for P may exist in a number of Midsouth rice fields. Soil test P has not proven to be a reliable indicator of the need for P fertilization in dry-seeded, delayed-flood rice production systems. Tissue testing for P at pre-flood can identify possible P deficiencies in rice.

Proper P nutrition is critical for producing maximum rice grain yields. Phosphorus promotes vigorous early plant growth and development of a strong root system. Maximum tillering is also dependent on P. Often, P deficiency in rice is referred to as a "hidden hunger" because the symptoms are not apparent unless deficient plants are directly compared to sufficient plants (**See photo**). When compared to healthy rice of the same age, P deficient rice is characterized by an abnormal bluish green color of the foliage with poor tillering, slow leaf canopy expansion, and slowed maturity. When such plant comparisons are not available, plant tissue testing is the best tool for diagnosing P deficiency.

Beginning in 2004, a 3-year P evaluation was conducted at the Missouri Rice Research Farm located near Qulin in Dunklin County, on a Crowley silt loam (fine, montmorillonitic, thermic Typic Albaqualf). This location has been in a rice/soybean rotation for over 15 years. A dry-seeded, delayed-flood rice production system was employed, with plots in a new area each year. These areas had similar pH (6.8), ammonium acetate-extractable K (135 lb/A), organic matter (1.8%), and CEC (10.0 meq/100 grams) levels, but different Bray P-1 levels each year (2004, 38 lb/A; 2005, 8 lb/A; and 2006, 32 lb/A). In 2004 and 2006, a maintenance application of 25 lb P_2O_5/A was recommended, while in 2005 an 85 lb P_2O_5/A application was recommended. A randomized complete block experimental design with four replications was employed each year. The plot size was 25 ft. by 10 ft. All methods of water management and weed and insect control were the standard practices for cultivating dry-seeded, delayed-flood rice in Southeast Missouri.

Direct comparison of P sufficient (left) and P deficient (right) rice plots at pre-flood.



Rate,	2004	2005	2006
0	164	119	120
25	164	130	135
50	174	133	136
100	183	138	141
LSD 0.10	5	17	10
CV%	5.8	11.1	5.8

[1]Average annual net return/A (gross-fertcost); \$0.25/lb P_2O_5; \$4.50/bu rice

Figure 1. Average rice grain yields for pre-plant P treatments in 2004-2006, Missouri.

Three pre-plant rates of P_2O_5 (25, 50, and 100 lb/A) as triple superphosphate (TSP) were compared to an untreated check. These treatments were applied and incorporated with tillage immediately before rice was seeded. A 50 lb P_2O_5/A rate of TSP applied at one of three times (pre-flood, internode elongation, or early boot) was also evaluated. Soil and plant tissue samples were collected from each plot prior to flood establishment. Soil samples were collected by compositing 12 individual cores representing a 0 to 6 in. depth. Whole, above-ground tissue samples for P determination were collected from one row-foot in the second drill row from the outside edge of each plot. Rice tissue samples were dried at 100°C, ground, and digested with sulfuric acid (H_2SO_4) and hydrogen peroxide (H_2O_2). Phosphorus concentration was determined colorimetrically using a spectrophotometer. At maturity, grain was harvested from the center 5 ft. of each plot. Moisture percentage of grain at harvest was measured in each plot and yields were adjusted to a 12.5% moisture basis.

Pre-plant P fertilization significantly increased yield in each year (**Figure 1**). However, visual identification of P deficient plots was possible only with a direct comparison with P-sufficient plots. The greatest yield each year was obtained with the 100 lb P_2O_5/A rate applied pre-plant. The greatest returns with P fertilization oc-

Abbreviations and notes for this article: P = phosphorus; K = potassium; CEC = cation exchange capacity; N = nitrogen.

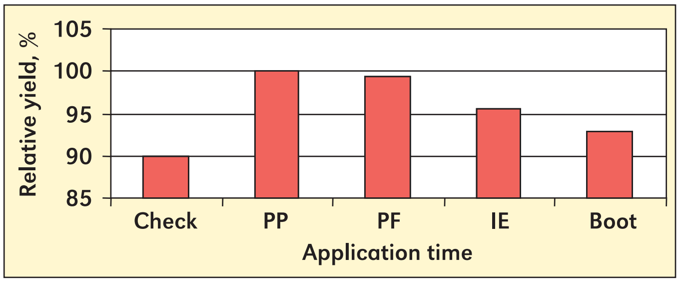


Figure 2. Average relative yields obtained by adding 50 lb P_2O_5/A at midseason timings, 2004-2006. (pp = pre-plant, pf = pre-flood (V5) growth stage, IE = internode elongation (R0) growth stage, boot = R2 growth stage)

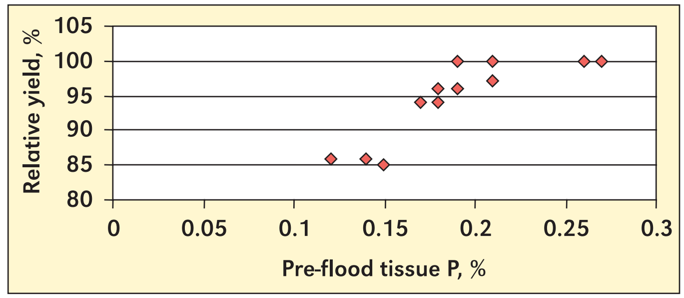


Figure 3. Relationship between whole-plant (aboveground), pre-flood tissue P concentration (%) and relative yield.

curred at 90 lb P_2O_5 /A, generating an average annual net return (gross-fertilizer cost) of $670/A compared to $605/A where no P was applied.

When the 50 lb P_2O_5/A pre-plant application was compared to 50 lb P_2O_5/A applied later in the growing season, an interesting relationship emerged (**Figure 2**). In terms of relative yields, the pre-flood application timing was able to capture 99% of the yield potential of the pre-plant timing, statistically equivalent. The subsequent application timings, internode elongation and boot, (averaged across all P rates) were able to capture progressively less of the yield potential (95 and 92%, respectively). The boot application was statistically equal to the untreated check (alpha = 0.10). This indicates that rice producers have a window of opportunity to correct a P deficiency, if it can be identified by pre-flood tissue sampling.

In the dry-seeded, delayed-flood rice production system commonly employed in the Midsouth U.S., rice is grown to the first tiller growth stage, N fertilizer (as urea) is applied to dry soil, and a permanent flood is then established. Supplemental N may be applied later in-season as needed. As the pre-flood urea-N is applied with ground-based equipment, a piggy-back P application would present a materials-only expense. Once a field is flooded, fertilizer applications must be made by airplane, which would raise costs an additional $5 to $10/A above materials. These factors combine to make a pre-flood P application the most cost-effective in-season timing.

Two methods of evaluating P fertility status (soil and tissue sampling) at pre-flood were compared. Tissue testing provided a better prediction of yield than soil testing (**Figure 3**). Whole-plant tissue P levels greater than 0.18% were consistently correlated with maximum rice yields (relative yields greater than 95%). Soil P testing at pre-flood was much less successful in yield prediction (relative yield or absolute yield). Consequently, tissue testing would be the preferred method for diagnosis and prediction of rice P status.

To properly collect a tissue sample at pre-flood, rice producers should select areas within each field that are relatively uniform (similar crop history, soil texture, fertilization history). These areas should represent management units (zones) which may be fertilized separately. The above-ground tissue should be collected from one foot of drill row at four or five randomly-selected locations within each unit. Care should be taken to prevent contamination with soil, since this will influence the results. The basal portion of the sample may be washed with distilled water if soil contamination is suspected. Samples should be placed in paper containers (not plastic) to allow drying during subsequent handling and transport to a qualified tissue testing lab for analysis. Proper labeling of samples ensures consistent identification later. When selecting a lab, close attention should be paid to turn-around time. Results not returned to producers in a timely manner may cause delays in flood establishment or an inability to capture the pre-flood application timing window.

Based on this 3-year study, producers have the opportunity to correct P deficiency in rice as late as pre-flood and still obtain maximum yield benefit. In 2004, the untreated check yielded 164 bu/A, which would be an acceptable yield for most producers. Our research documented a significant yield increase with P additions and points to a "hidden hunger" situation. The results of our work indicate that tissue testing for P at pre-flood could have indicated a possible P deficiency. Producers should consider tissue testing rice fields at pre-flood and apply P fertilizers if the tissue P level is 0.18% or below. BC

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Maximizing Phosphorus Removal with Winter Cereal/Corn Double-Crop Forage Production

By Bradford D. Brown

Maximizing P removal from soil with intensive cropping can sometimes be advantageous for manure management. Double-cropping with winter forages and silage corn increased total forage production, increased P removal, and reduced soil P concentrations more than with corn alone.

Surface water quality concerns have sometimes led to P-based limits on manuring rates, where higher manuring rates are limited by P removed in harvested crops. Since harvested forages remove large amounts of P, increasing their production will improve the P balance in manured fields, which can: 1) slow or avoid soil P enrichment, 2) enable herd size to be maintained or expanded to an economic scale, 3) avoid the need for increased land resources, or 4) hasten the soil test P decline in P-enriched soil.

Fall-planted small grain cereals produce forage during the cooler part of the year without sacrificing corn production. Harvesting winter cereals at the boot stage, rather than soft dough, produces less biomass but allows corn to be planted at normal planting dates. Since P accumulation precedes biomass production, a boot stage harvest does not sacrifice P uptake and removal nearly as much as it does biomass. The objective of this study was to evaluate the winter cereal/silage corn double-crop system for its potential in southern Idaho to increase both forage production and P removal over that with corn alone.

A 3-year irrigated double-crop (small grain harvested at boot stage followed by silage corn grown in a single year) forage study was conducted on a Greenleaf-Owyhee silt loam (Xeric Calciargid) at the University of Idaho Parma R & E Center. The double-cropping involved three winter (barley, wheat, and triticale) and two spring cereals (wheat and triticale), fall planted at three seeding rates (100, 150, or 200 lb/A) and followed with silage corn. Two non-planted fall treatments were also included: silage corn alone and one kept bare for the duration of the study.

The site had an initial P concentration of 20 ppm bicarbonate-extractable P and then received 366 lb P_2O_5 /A (as 0-45-0). Winter-grown cereals were fertilized on the soil surface with 100 lb urea-N/A in the spring of 1999 and 2000, and with 200 lb N/A in 2001. Fertilizer N for corn was sidedressed as urea in multiple applications totaling 200 lb N/A in 1999, 270 lb N/A in 2000, and 200 lb N/A in 2001. Corn and winter cereals were furrow irrigated as needed. Soil samples were routinely taken from each plot during the experiment. Forage and corn yields and tissue composition were measured using standard methods.

Dry matter yield differed for the small grain cereals depending on the year (**Figure 1**). Dry matter production over the 3 years was higher for winter triticale (9 tons/A) than for winter or spring wheat and winter barley (average 7 tons/A). Winterkill reduced winter barley stands by 23% and spring wheat stands by 45% in 1999, resulting in considerably less forage than with spring and winter triticale or winter wheat. Spring wheat yield rebounded the second year and did not differ significantly from winter triticale, and exceeded the yield for winter wheat. Winter wheat was consistently lower yielding than either winter or spring triticale. Spring genotypes, in the absence of winterkill, were as productive as the winter genotypes. Seeding rates higher than 100 lb/A were required to maximize winter forage yield.

Triticale plots are shown at the research site.

Mean winter forage P uptake over the 3 years was greatest for winter triticale, but P uptake differed among forages depending on the year (**Figure 2**). Accu-

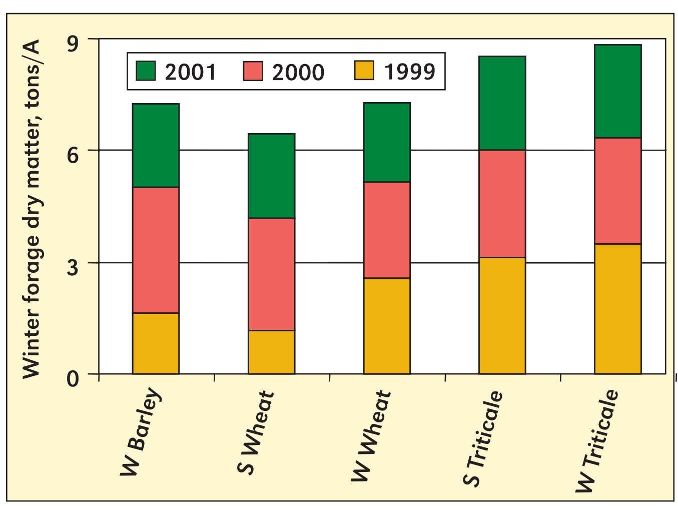

Figure 1. Cumulative winter forage production when harvested at the boot stage for 3 years.

Abbreviations and notes for this article: P = phosphorus; ppm = parts per million; N = nitrogen.

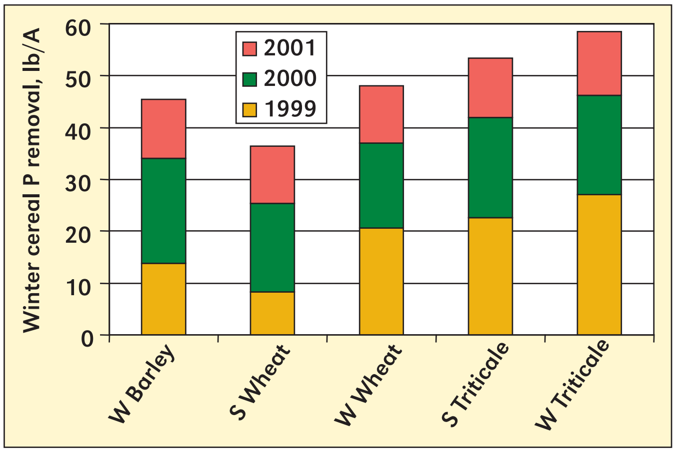

Figure 2. Cumulative P removal in winter cereals harvested at the boot stage for 3 years.

mulation of P by winter barley and spring wheat was reduced in 1999 due to winterkill. With no winterkill, winter forages differed little in P uptake. Mean winter forage P concentrations declined from the first year high of 0.39% P in 1999, to 0.32% in 2000, and to 0.25% in 2001. This decline is assumed to be due to reduced available P. Winter forage P uptake also declined with successive harvests, the decline ranging up to 46% for winter wheat and 54% for winter triticale. Average P uptake across all winter forages declined 38% from 2000 (23 lb P/A) to 2001 (14 lb P/A). Declining P uptake resulted from both lower biomass and declining forage P concentrations.

It is not clear if declining soil P limited dry matter production. Forage P concentrations in 2001 were above those previously cited as necessary for the production of grain (0.15 to 0.2% P), but this critical range may not be appropriate for boot stage forage production.

The presence of winter forages in 1999 significantly affected the stand and vigor of the corn. Corn stands were poorest (reduced 25 to 32%) and vigor lowest when it was no-till planted into greater stubble of the winter

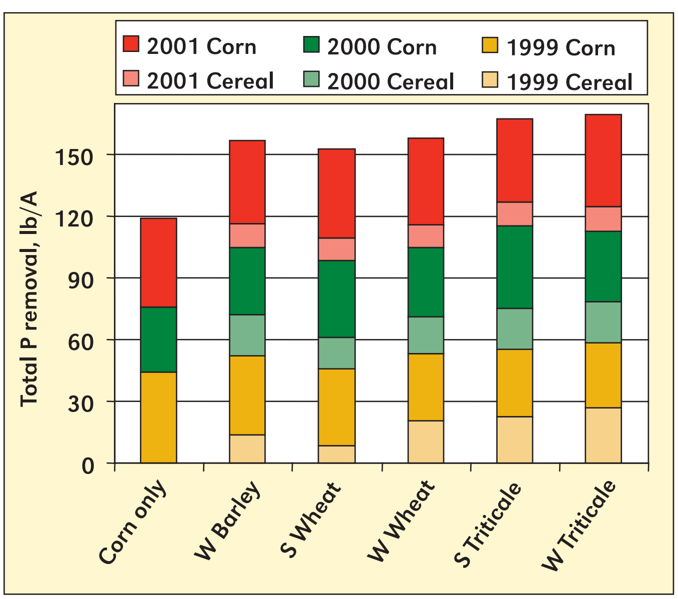

Figure 3. Total P removal in corn and winter cereals over 3 years.

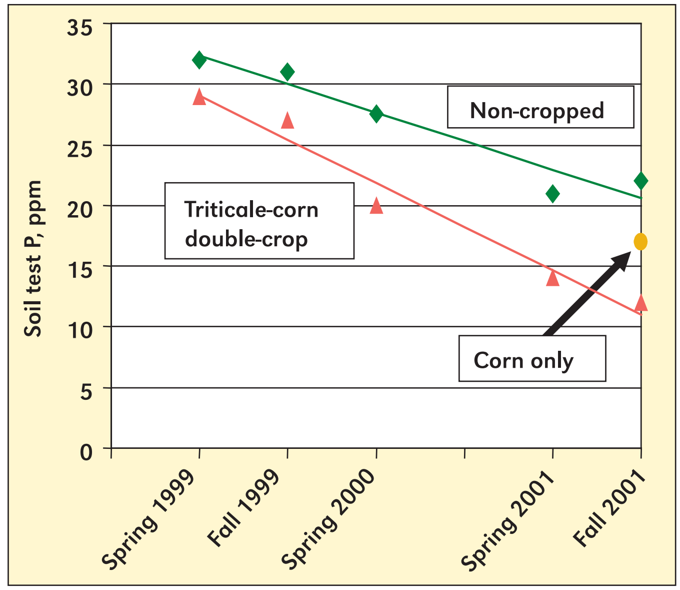

Figure 4. Decline in soil P concentrations in triticale/corn double-cropped or non-cropped plots during a 3-year experiment.

cereals unaffected by winterkill. Corn vigor was also reduced by triticale regrowth. Corn stands and corn yields were not affected by previous winter forages in subsequent years with rototilling. In contrast to winter cereals, corn forage P concentrations and uptake did not decline with successive harvests. Total biomass yield after 3 years of the double-crop (with the exception of the winter wheat/corn combination) was 10 to 16% and P removal was 40% greater than corn alone (**Figure 3**). For the double-cropped treatments, as much P was harvested during the 3 years as was initially applied. To put this in perspective for manuring, an additional 3-year uptake of 50 lb P/A by the winter cereals would allow application of 5 tons/A more broiler litter or 23 tons/A more fresh dairy manure.

Crop P removal measurements in this study may be conservative compared with highly P enriched soils. For highly enriched soils, winter forage P concentrations likely would not decline as rapidly nor winter forage yields be as limited by reduced P as they were in this study. Winter forage P concentrations and P uptake were more sensitive to declining soil test P than corn, which may be related to cooler soil temperatures during the period of winter forage growth.

Soil P concentrations declined during the study in both cropped and non-cropped treatments, but the decline was greater with double-cropping than with corn alone (**Figure 4**). As expected, the applied P became gradually less soluble over time due to factors such as P sorption, precipitation, and incorporation into organic matter. BC

Additional details on this study can be found in: Brown, B. 2006. SSSA Journ. 70:1951-1956.

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NORTH AMERICA

Foliar Potassium Improves Cantaloupe Marketable and Nutritional Quality

By G.E. Lester, J.L. Jifon, and W.M. Stewart

Potassium is important in optimizing both crop yield and economic quality. Root activity and K uptake are generally reduced during the reproductive phase of crop development. This study has shown that supplementing sufficient soil K with additional foliar K applications during cantaloupe fruit development and maturation improves fruit marketable quality by increasing firmness and sugar content, and fruit human-health quality by increasing ascorbic acid, beta-carotene, and K levels.

Potassium is required by plants in much greater amounts than other mineral nutrients, with the exception of N. Potassium uptake by plants from soil solution is influenced by several factors, including soil moisture conditions, pH, texture, aeration, temperature, and balance with other nutrients. Plant development stage also influences the capacity for K uptake. More K is taken up during the vegetative growth stages when roots are actively growing than in fruit growth (reproductive) stages when root growth is inactive (Beringer et al., 1986).

Developing fruit are stronger sinks for photoassimilates than roots and other vegetative tissues. This competition for photoassimilates reduces root growth and energy supply for nutrient uptake (Marschner, 1995). Thus, during reproductive development soil K supply may not be adequate to support crucial processes that ultimately determine yield and quality. More specifically, muskmelon (cantaloupe) has some of the highest fruit K concentrations among fruit, hence developing melons have a high demand for K and often rely on re-translocation from vegetative tissues (Williams and Kafkafi, 1998).

Previous research has demonstrated that this apparent K deficiency during fruit development and maturation can be mitigated through supplemental foliar K applications to netted cantaloupe (Lester et al., 2005).

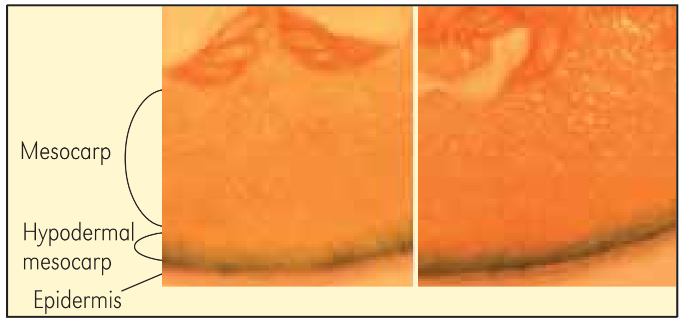

Figure 1. Control fruit in the left photo averaged 7.1% SSC and 18 ppm beta-carotene. The KM+S treated fruit in the right photo averaged 10.2% SSC and 26 ppm beta-carotene.

The objective of this glasshouse study was to further investigate the effect of foliar K application on cantaloupe quality parameters and to compare two K sources: a glycine amino acid complexed K...Potassium Metalosate™ (KM)... and KCl, both applied with and without a surfactant.

Netted, orange-flesh cantaloupe 'Cruiser' fruit were grown in a glasshouse at the USDA-ARS Kika de la Garza Research Center in Weslaco, Texas, in the fall of 2004 and spring of 2005. Procedures previously described by Lester et al. (2005) were used. Plants were grown in a commercial potting medium in 15-liter pots, watered daily through an automated drip irrigation system. A complete water soluble fertilizer was delivered through fertigation twice per week during vegetative and fruit development stages to ensure that soil nutrient status was not limiting. Immediately after fruit set (anthesis) and up to fruit maturation (abscission), entire plants including fruit were sprayed to runoff with one of the following: 1) KM solution; 2) KCl solution; 3) KM

Table 1. Influence of growing season (spring or fall) and two sources of supplemental foliar K (KM and KCl), applied with or without a surfactant (S), on fruit K concentration and firmness. Epidermis refers to the peel, hypodermal mesocarp is the outer green pulp of the melon and the mesocarp is the edible pulp.

	Tissue K concentration, % fresh wt.			Fruit tissue firmness, Newtons, N	
Treatment	Epidermis	Hypodermal mesocarp	Mesocarp	External	Internal
Fall 2004					
KM	0.330 b[1]	0.225 b	0.246 a	19.7 a	11.4 a
KCl	0.354 a	0.207 bc	0.230 b	19.7 a	10.7 a
KM+S	0.330 b	0.250 a	0.241 a	18.8 a	11.5 a
KCl+S	0.335 b	0.225 b	0.245 a	19.2 a	12.0 a
Control	0.329 b	0.189 c	0.217 c	14.5 b	8.6 b
Spring 2005					
KM	0.364 b	0.302 b	0.273 a	15.8 a	10.3 ab
KCl	0.449 a	0.274 bc	0.255 b	15.7 a	9.6 b
KM+S	0.372 b	0.312 ab	0.260 b	16.8 a	10.0 ab
KCl+S	0.364 b	0.340 a	0.260 b	17.7 a	11.1 a
Control	0.365 b	0.266 c	0.235 c	12.7 b	7.5 c

[1]Means within a column and within a season followed by the same letter are not significantly different using LSMEANS comparisons at $p \leq 0.05$, n = 10.

Abbreviations and notes for this article: K = potassium; N = nitrogen; KCl = potassium chloride; ppm = parts per million; SSC = soluble solids concentration

Table 2. Influence of growing season (spring or fall) and two sources of supplemental foliar K (KM and KCl), applied with or without a surfactant (S), on fructose, glucose, sucrose, total sugars, relative sweetness, and SSC of netted muskmelon 'Cruiser'.

	Sugar, % fresh wt.				Relative sweetness[z],	SSC,
Treatment	Fructose	Glucose	Sucrose	Total	% sucrose equiv.	%
Fall 2004						
KM	1.92 a[1]	1.08 a	3.36 ab	6.36 b	7.57 b	9.7 a
KCl	1.90 a	1.11 a	3.21 ab	6.22 b	7.46 b	9.2 b
KM + S	1.75 b	1.08 a	4.12 a	6.95 a	8.03 a	9.8 a
KCl + S	1.73 b	1.00 a	3.62 ab	6.35 b	7.43 b	9.7 a
Control	1.68 b	0.99 a	2.90 b	5.57 c	6.61 c	8.9 c
Spring 2005						
KM	1.45 a	0.94 bc	3.13 ab	5.53 a	6.40 a	9.6 b
KCl	1.29 c	0.91 c	3.19 ab	5.40 a	6.15 b	9.7 b
KM + S	1.38 b	0.96 ab	3.27 a	5.62 a	6.42 a	10.1 a
KCl + S	1.38 b	1.00 a	3.15 ab	5.54 a	6.33 ab	9.9 ab
Control	1.24 c	0.90 c	2.98 b	5.12 a	5.68 c	8.8 c

[1]Means within a column and within a season followed by the same letter are not significatly different using LSMEANS comparisons at $p \leq 0.05$, n = 10.

[z]Relative sweetness = 1.8 (mg/g fresh wt. fructose) + 0.7 (mg/g fresh wt. glucose) + 1.0 (mg/g fresh wt. sucrose).

plus a nonionic surfactant (KM+S); 4) KCl plus surfactant (KCl+S); or 5) deinonized water. Solution concentration for all K treatments was 800 ppm K (0.08% K).

Foliar K application generally resulted in higher K concentrations in fruit mesocarp (edible pulp) tissue compared to non-treated control fruit (**Table 1**). However, in both spring and fall, the effects of K source and surfactant use on fruit tissue K concentrations were generally not consistent. External and internal firmness of fruit from plants receiving foliar K were significantly higher than those from control plants in both seasons, regardless of surfactant use or K source (**Table 1**). The K-related increase in fruit firmness was associated with increased tissue pressure potential (data not shown). Pressure potential was positively correlated with SSC, total sugars, fruit sucrose, and glucose concentrations.

Table 3. Influence of growing season and two sources of supplemental foliar K (KM and KCl), applied with or without a surfactant (S) on total ascorbic acid and beta-carotene concentrations of netted muskmelon 'Cruiser' fruit.

	Total ascorbic acid	Beta-carotene
Treatment	-------- ppm fresh wt. --------	
Fall 2004		
KM	36,400 a[1]	30.9 a
KCl	33,500 b	26.6 c
KM+S	35,200 ab	29.6 ab
KCl+S	36,000 ab	28.6 b
Control	30,000 c	25.7 c
Spring 2005		
KM	26,800 b	22.9 b
KCl	28,000 ab	23.1 b
KM+S	28,300 a	25.1 a
KCl+S	27,000 ab	26.6 a
Control	24,200 c	21.8 c

[1]Means within a column and within a season followed by the same letter are not significatly different using LSMEANS comparisons at $p \leq 0.05$, n = 10.

Total fruit sugars (osmolytes) were generally higher in K treated fruit compared to controls and also slightly greater in fall than in spring grown fruit (**Table 2**). Fruit SSC was significantly greater in K-treated fruit, regardless of season. Fruit sucrose, glucose, and fructose levels were generally increased by foliar K fertilization. Relative levels of sucrose and fructose in fruit has important implications for consumer preference since fructose is perceived to be up to 80% sweeter than sucrose. Relative sweetness of melons was increased by supplemental foliar K application compared to controls (**Table 2**). The increase in fructose: sucrose ratio indicates that foliar K fertilization has the potential to improve a key consumer preference attribute of cantaloupe.

Ascorbic acid (vitamin C) and beta-carotene (vitamin A) were generally higher in fruit treated with K than in control fruit (**Table 3 and Figure 1**). However, there were no consistent K source effects on these quality parameters. The beneficial effects of supplemental K probably resulted from a combination of improved leaf photosynthetic CO_2 assimilation, assimilate translocation from leaves to fruit, improved leaf and fruit water relations, increased enzyme activation and substrate availability for ascorbic acid and beta-carotene biosynthesis, all associated with adequate K nutrition (Gross, 1991, Hopkins, 1963). Differences between the two K sources were minimal and use of a surfactant tended to have a positive effect on K response. These quality improvements were obtained by implementing a simple management tool that growers can adopt anywhere in the world. BC

IPNI/FAR Project TX-51F

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Testing Turfgrass Soils

By D. Soldat, A.M. Petrovic, R. Rao, and T.W. Bruulsema

Best management practices for turfgrass fertilizer ensure a vigorous soil cover while minimizing risk of nutrient and sediment losses that harm water quality. While soil testing of home lawns is seldom practiced, a recent survey indicates that two-thirds of turfgrass soils in New York may be limited by P, K, or pH. About 20% require P fertilizer.

Fertilizers, applied with the right management, can green lawns without greening lakes. Phosphorus—a nutrient that can stimulate algal blooms—can also be an essential component of such fertilizers. Soil testing provides information critical to deciding whether or not to include it.

Turfgrasses are well known for their ability to protect against soil erosion. They break the impact of raindrops, reduce runoff by increasing the amount of water that filters into the soil, and hold the soil from moving. Since erosion puts both sediment and nutrients in streams, turfgrasses play a key role in protecting water quality.

All plants, including turfgrasses, require nutrients to grow. Their vigor depends on the level of soil nutrients. Maintaining a vigorous lawn has been shown to reduce erosion and runoff compared to poorly maintained lawns. So while it may seem contradictory, you may need to apply P to turf in order to reduce P loss in runoff.

How can you tell if your lawn needs P? Few people test the soil for their lawns, and soil testing is not commonly a part of commercial lawn care programs. The cost of a soil test is not high—US$10 to 30—but it seems that many people feel the size of their lawn doesn't justify the cost and the time involved.

The Cornell University Nutrient Analysis laboratory analyzes over 800 turfgrass soil samples each year, but a recent survey of New York state reported a total of 3.7 million residential lawns, comprising 2.8 million acres. Other labs also test turfgrass soils. But the current rate of soil testing indicates most residential lawns are not tested.

Most residential lawns do not require sampling as frequently as agricultural fields. If clippings are returned, most of the P and K taken up by the grass is returned to the soil, and soil test levels will not change much over time. However, if a lawn is never sampled, it can be hard to judge whether a lawn's performance is limited by those nutrients.

A recent summary of New York turfgrass soil tests, based on samples submitted to the Cornell laboratory between 2001 and 2005, included 3,303 home lawns and 500 athletic fields. Since it was not designed as a random sample of these soils, limitations apply to its interpretation, but it can be assumed to represent some of the better-managed turfgrass soils of the state.

The summary indicated that soil fertility levels were often high, and distributions for home lawns and athletic fields were similar. Around 60% of soils tested high or very high for P (**Table 1**). Likewise, 64% of soils tested high or very high for K (**Table 2**). However, a substantial number of soils tested in the low range, a level where applying the nutrient usually improves turfgrass vigor, or in the medium range, a level where it could.

Maintaining a vigorous and healthy lawn has been shown to reduce erosion and runoff compared to poorly maintained lawns.

Another soil attribute that may limit turfgrass vigor is soil pH. The distribution of pH levels in from the same survey is shown in **Table 3**. Turfgrass species differ in their pH preferences. Kentucky bluegrass

Table 1. Soil test P levels in New York state turfgrass soils, 2001-2005.

Soil test category	Soil test P[1], ppm	%
Low	0 - 2	20
Medium	2 - 4	19
High	4 - 20	41
Very high	> 20	19

[1]Morgan soil test, sodium acetate extractant.

Table 2. Soil test K levels in New York state turfgrass soils, 2001-2005.

Soil test category	Soil test K[2], ppm	%
Low	0 - 50	18
Medium	50 - 75	18
High	75 - 120	31
Very high	> 120	33

[2]Soil test K categories depend on Soil Management Group. Ranges in ppm shown are for Group 4 soils (sands and coarse loams). Percentages were calculated from the appropriate ranges for each soil group.

Table 3. Soil pH distribution in New York state turfgrass soils, 2001-2005.

Soil pH range	% of soils
<5.5	14
5.5-6.0	18
6.0-6.5	16
6.5-7.5	39
>7.5	13

Abbreviations and notes for this article: P = phosphorus; K = potassium; ppm = parts per million.

grows best when soil pH is between 6.0 and 7.0, while fine fescues grow best in the more acidic range of 5.5 to 6.0.

Putting the three attributes together—P, K, and pH—two-thirds of the soils tested showed a possible limitation arising from one or more of the three. Soil testing would benefit the performance of the majority of lawns. It also identifies lawns where further P inputs are not required, helping to protect the environment.

Since P and K are nutrients that accumulate in the soil, fertilizing usually builds up the soil test level, as long as the amount applied exceeds removal. If all clippings are removed from a vigorous lawn, the annual nutrient removal amounts to about 0.5 to 2 lb of P_2O_5 and 1 to 5 lb of K_2O per thousand square feet. If the clippings are left on the sod, most of the P and K is recycled. Where soil tests are low, continued fertilization will eventually increase them. It is unnecessary to continue building up soil test P once it is in the high range.

Does a buildup of P in a turf soil increase the risk of runoff polluting water? This question was investigated in research at Cornell University. In the fall of 2003, 68 plots were monitored for runoff water. Half of the plots were bare soil, and the other half had turf. The Morgan soil test P levels in these plots ranged from 4 to 20 ppm in the top 6 in., and from 8 to 40 ppm in the top inch.

The presence of turfgrass reduced the P load in runoff from these plots by 36%. For bare soils, the P load in runoff increased six-fold with increasing soil test. Where the soils were protected by turf, there was no significant increase in runoff P load as soil tests increased.

These data suggest that buildup to a soil test P level sufficient for turfgrass nutrition would not constitute a risk to water quality in terms of runoff P load. Of course, it would be important to ensure that P fertilizer is applied using best management practices:

- At recommended rates
- Avoiding spillage onto paved surfaces
- Keeping away from water flow paths
- In balance with other nutrients
- With appropriate timing BC

IPNI/FAR Project NY-07F

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2007 InfoAg Conference Schedule

Dates for two regional Information Agriculture Conferences and the biennial international InfoAg Conference were announced earlier by Foundation for Agronomic Research (FAR) President Dr. Harold F. Reetz and IPNI President Dr. Terry L. Roberts.

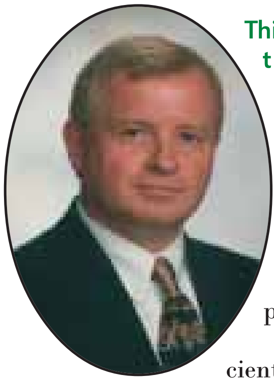
InfoAg Mid-South is set for February 7-8 at the Bost Extension Center, Mississippi State University, Starkville. This regional event will focus on the application of precision technology and information management for cotton, rice, soybeans, and other crops of interest in the Mid-South.

InfoAg Northwest is scheduled for February 20-21, at the Three Rivers Convention Center in Kennewick, Washington. This is a first-time conference in the Northwest agricultural region. InfoAg Northwest will highlight precision equipment, practices, and the people who have successfully incorporated them into their grain crop, fruit, vegetable, and potato production systems.

InfoAg 2007, the popular national/international edition of the Information Agriculture Conference, is set for July 10-12. The location is the Crowne Plaza in Springfield, Illinois, the same as for 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.

For more information about the 2007 InfoAg Conferences, please visit the website: >**www.infoag.org**<. Or call: 217-762-8655. BC

A Message to Readers of *Better Crops with Plant Food*



This issue of *Better Crops with Plant Food* marks a new chapter in the long history of this unique publication. A new organization called the International Plant Nutrition Institute (IPNI) is now the owner and publisher. A list of the founding members of this new Institute appears on page 2.

IPNI

The Potash & Phosphate Institute (PPI) was the owner and publisher of *Better Crops with Plant Food* for many years. With the formation of IPNI, PPI no longer exists. However, the programs and staff that were assembled by PPI are now part of IPNI. New and expanded programs in key regions of the world are expected.

The primary mission of PPI was related to P and K. However, the mission of IPNI is expanded to include N, S, and other nutrients in addition to P and K.

IPNI will be science-based to better understand and share information on how to most efficiently and effectively use all available sources of plant nutrients to provide for the food, fiber, feed, and fuel needs of the growing human family. We will seek new information through scientific discovery and evaluation, and apply this knowledge in ways that are protective of the environment, preservative of natural resources, economically sustainable, and socially acceptable. Another goal is to educate industry, governments, and the public about the most current information on the safe and appropriate use of plant nutrients in food, fiber, feed, and fuel production.

Historical Note

Better Crops with Plant Food has had a long and proud history of publishing sound, dependable, accurate, and useful information on crops, soils, fertilizers, and related subjects. Many readers may not realize that *Better Crops* first began publication in 1923. *Plant Food* was the name of a second publication that came into print in January 1926. Because the mission of the two publications was so similar and for other reasons, the two magazines were combined and the first issue of *Better Crops with Plant Food* was published in July 1927.

A New Format

For many years, *Better Crops with Plant Food* was published in a 6 x 9-in. page size. While this was unique, the format also had limitations regarding the layout and presentation of articles and other content. Beginning with this issue, the page size has increased to 8½ x 11-in. Some other changes in style, listing of references with articles, and the mix of international and North American articles are intended to make the magazine even more effective.

Incidentally, articles from each issue of *Better Crops with Plant Food* will now be found at the IPNI website: >**www.ipni.net**<. Back issues can also be found at the same URL.

Moving Forward

Tremendous changes in agriculture, the fertilizer industry…and the world…have occurred in recent decades. No one can predict the future, but we expect IPNI and *Better Crops with Plant Food* will adapt to the new realities and serve well for many years to come.

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