BETTER CROPS
WITH PLANT FOOD

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2004 Number 2

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- Phosphorus and Phytochemicals

...and much more!

BETTER CROPS WITH PLANT FOOD

Vol. LXXXVIII (88) 2004, No. 2

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BETTER CROPS WITH PLANT FOOD
(ISSN:0006-0089) is published quarterly by the Potash & Phosphate Institute (PPI). Periodicals postage paid at Norcross, GA, and at additional mailing offices (USPS 012-713). Subscription free on request to qualified individuals; others $8.00 per year or $2.00 per issue. POSTMASTER: Send address changes to Better Crops with Plant Food, 655 Engineering Drive, Suite 110, Norcross, GA 30092-2837. Phone (770) 447-0335; fax (770) 448-0439. www.ppi-ppic.org.

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Will We Run Out of Phosphorus?

By David W. Dibb

The question occasionally arises as to whether the world will eventually use all the supply and reserves of an essential nutrient such as phosphorus (P). This article gives a brief explanation of why there is no danger of running out of P sources.

Will we run out of P fertilizer for food production? The short and definitive answer is "no." How can that assertion be absolute? Phosphorus is one of the most abundant basic mineral elements on the earth. Phosphorus is a necessary component for all living organisms. The form of P can be changed, the location can be changed, but the total mass (the total existing amount of P) is unchanged.

The availability of P for use in food production…and thus availability to living organisms…depends on our ability to recover P from wherever it resides and place it near the plants that produce food and become the energy source for all living things…in a form plants can use.

Currently, there is abundant P available to produce food. In large part, this is because we have learned to extract P from large mineral phosphate rock deposits, convert it to a form that is more available to plants, and deliver it to farmers, who apply the P to their crops and produce our food. This process is the foundation of the current commercial P fertilizer industry.

Concentrated phosphate rock deposits are the main source of P fertilizers today.

Some of the P we need to make our bodies function properly comes to us directly in vegetables, fruits, grains, etc. Some comes to us indirectly through animal products such as meat, milk, and eggs. Some is consumed in vitamin or mineral supplements. All of this P originally came from one of the naturally occurring mineral P deposits…whether from the sources that were concentrated in phosphate rock deposits, or from those diffused in soils during their natural development processes. As crops are grown and as P is removed from soils, P has to be replaced to sustain the potential to produce more food. This replacement represents the current practice of crop fertilization.

But, what about when all of these mineral deposits we are mining are depleted? Will that happen soon? When it does, will we run out of P for food production? Again, the definitive answer is "**NO**." To understand why, we need to take a look at historical uses and sources of P for food production, what is happening today, the current reserves of P, and some possible other sources of P for the future. With this perspective, we will be able to understand why the world will not run out of P.

First, consider the historical use of P in food production. We all know the story of how the Native Americans showed the early Pilgrims in colonial times how to put a fish in the hole where corn seeds were planted in order to produce more abundant crops. As the fish decomposed, needed P and other nutrients were supplied to the corn plants. Others learned that manures from animals would also supply some of the P needs for crops. Crop residues contain P and, if returned to the soil, helped maintain the P supply. As human and animal populations increased, there were not sufficient supplies of fish, manure, or crop residues to maintain soil fertility and productivity. Many soils were depleted of P and other nutrients. In fact, the early migration of people from the east coast of the U.S. to more fertile lands further west was in part because of the depletion of soil fertility of those early-farmed lands. The inability of those who grew crops to replace the nutrients they had removed resulted in those lands, which were depleted of nutrients, being abandoned for more productive lands in the frontier.

New sources of P were found. Bones were known to be rich in P. Ground bonemeal from slaughtered animals became a source of nutrient P. Blood meal, fishmeal, and other sources of P became commercially available. Supply was insufficient to sustain P levels and the productivity of soils declined. Advances in chemistry opened up a new, abundant source of P. Newly discovered concentrated phosphate rock deposits could be treated with acids similar to those occurring naturally in soils. Phosphorus could be made available to plants and could be concentrated and transported in a highly efficient form to the farmer. This was the birth of today's commercial P fertilizer businesses. Some phosphate rock deposits have been mined and depleted and other commercially viable deposits have been located and started into production. Other deposits remain unused… and under current economics are not considered useful. Under newer extraction and process technology, and with different economics, many of these deposits will later become sources of P.

As part of our historical look at P, compare today's known phosphate rock reserves to those of 50 years ago, and what the usage was then and now. See **Table 1.**

Several interesting facts emerge from this table and from supporting data:

- Since 1953, the world has mined a total of 5.5 billion tons of phosphate rock.
- Known reserves with today's economics are very large, about 3.3 billion tons more than they were 50 years ago.
- As economics and technologies change, additional known reserves will be made available, just as they have been since 1950.
- Reserves plus all other mineral P rock deposits that may potentially be economically feasible at some time in the future have been conservatively estimated at over 100 billion tons.

In today's economic environment, no one has any great incentive to explore for new P reserves. Any P reserves found today are probably the result of exploration for other products, such as petroleum, natural gas, and precious metals. With a specific focus on looking for P reserves, additional finds are possible.

Even if no other reserves are found and these known reserves are ultimately depleted, will we run out of P for food production? Again, the definitive answer is "**NO**." New technologies are even now being developed that could exploit other large sources of P. A couple of examples can give insight into where some of that P might come from.

Phosphorus exists naturally in all productive water bodies. If P were not there, aquatic life would not exist. Some water

Table 1. World reserves and annual mine production of phosphate rock.

Year	World reserves[1], billion metric tons	World mine production, million metric tons
1953	46.7	27.2
2003	50.0	138.0[2]

[1] World reserves include resources (measured plus indicated reserves and reserve base) that are exploitable with today's economics and technology, or have a reasonable potential for becoming economically available.

[2] Estimated

bodies have enhanced levels of soluble P, which could be 'mined' or extracted. Seawaters contain abundant dissolved P...estimated conservatively at more than 90 billion metric tons. Seawater is currently being processed to provide fresh, potable water through desalinization processes. Perhaps a simple additional step, when economically feasible, could be to extract and separate P, somewhere during this process, for later use in crop production. Similarly, wastewaters from sewage treatment plants can contain even higher levels of P. Technology is available for extraction of this P. Its development into fertilizer P and its return to replenish soils and produce food is only constrained by today's economics.

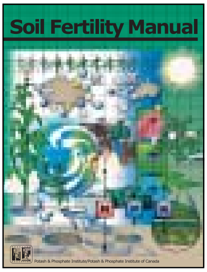
Just as the major source of P has changed from fish and manures in pilgrim times to processed rock phosphates in our time, the future may see a shift to P extraction from municipal waste waters and ocean waters as major sources...or through some other currently unknown process or procedure, from some other source. More likely, in the future, there will be a combination of all of these mentioned sources plus some new ones.

Just as today, when the more ancient methods are still incorporated with current methods to meet total needs, so will newer technology extract the P from where it resides, dependent on the economics, efficiencies, and ecology of each source. The P will be there for our use to produce the needed food. As in the past, human ingenuity will provide the answer. Will we run out of P for food production? The answer is sure and simple: **"NO."** BC

Dr. Dibb is President of PPI, located at Norcross, Georgia.

Soil Fertility Manual Revised Edition Available

A revised edition of the popular *Soil Fertility Manual* is now available from PPI. The publication has been used effectively in countless agronomic education and training classes, short courses, and workshops. It continues to be a useful resource for general study by groups and/or individuals. The Manual was first introduced in 1978 and has been revised and updated several times.



The 2003 edition has 200 pages and includes 11 chapters, plus a glossary and index. Two new appendix sections feature color photos of nutrient deficiency symptoms and tables of conversions and reference lists. The publication is 8 ½ x 11 page size, with functional wiro-ring binding. Also available for 3-ring binders.

Chapter titles in the revised edition include: Concepts of Soil Fertility and Productivity; Soil pH and Liming; Nitrogen; Phosphorus; Potassium; The Secondary Nutrients; The Micronutrients; Soil Sampling; Soil Testing, Plant Analysis, and Diagnostic Techniques; Fertilize for Profits; and Plant Nutrients and the Environment.

The *Soil Fertility Manual* is available for purchase at $25.00 each, with discounts for larger quantity orders. For more information or to order, contact: PPI, 655 Engineering Drive, Suite 110, Norcross, GA 30092-3837; phone (770) 825-8080; fax (770) 448-0439. E-mail: circulation@ppi-ppic.org. Check the PPI website at: >**www.ppi-ppic.org**<.

ONTARIO

Phosphorus and Phytochemicals

By T.W. Bruulsema, G. Paliyath, A. Schofield, and M. Oke

Phosphorus (P) has long been recognized by fruit and vegetable growers as a nutrient important for improving quality. Even in highly fertile soils, P sometimes increases the levels of health-functional phytochemicals like anthocyanins, flavonoids, and lycopene.

Phytochemicals—compounds made uniquely by plants—capture considerable media attention today, because many are linked to health benefits. Sometimes these health-functional compounds go by names such as nutraceuticals, functional food ingredients, etc.

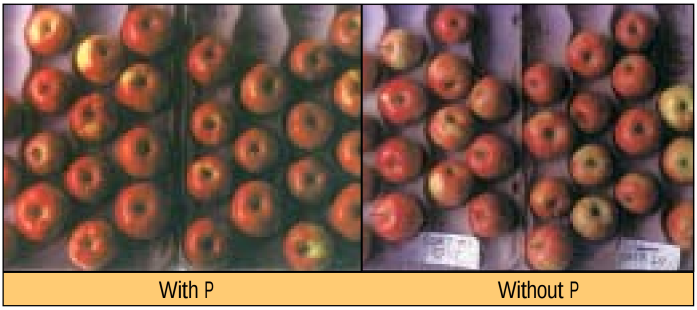
Flavonoids—such as quercetin and catechin—and isoprenoids—such as lycopene and carotene—are strong antioxidants. These phytochemicals are believed to be the principal agents in fruits, vegetables, and their processed products that impart anti-cancer properties and cardiovascular protection to humans.

Consumers are searching for foods rich in these compounds, and often look to organically produced foods or exotic herbal extracts. But the production practices that directly influence their levels in plants are not well known. We conducted research to determine the influence of adding more P than usual on the levels of phytochemicals in tomatoes and apples.

In well-nourished plants, most of the P is inorganic, stored within the cell in vacuoles. Vacuolar P keeps up a constant and rich level in the chloroplast, where biosynthesis begins. Every molecule produced comes out in a phosphorylated form—bonded to a phosphate molecule that gives it the energy it needs for further biosynthesis. It is well known that in a P deficient plant, biosynthesis is inhibited. What is less well known is whether higher levels of P stimulate higher or more specific biosynthesis of phytochemicals.

Apples

We applied P treatments to apple trees in an orchard south of Georgian Bay. The soil in this orchard was rich in P, testing 50 parts per million (ppm) Olsen-P. The grower did not normally apply P fertilizer. In 1999, red color in the apples increased in response to applied P, at rates supplying a total of 4 lb/A (foliar) and 40 to 120 lb/A (soil-applied) of P_2O_5 (**see photo**). The P treatments also increased sweetness (Brix) in both McIntosh and Red Delicious varieties, and farnesene (an aromatic flavor volatile) in Red Delicious only.


With P
Without P

Red Delicious apples at harvest in 1999, with and without soil-applied P.

However, in the McIntosh apples grown in 2000, there was no response to applied P in terms of color, anthocyanins, farnesene, or any other flavor volatiles. The 1999 season ended with warm sunny days and cool nights—conditions which can stimulate anthocyanin production. The 2000 season was more cloudy and not as cool in the nights. Weather conditions appear to influence the responses to added P.

Increased color suggests the activation of the pentose phosphate pathway, from which the precursor for flavonoids (erythrose-4-P, a four-carbon sugar) is derived. Flavonoids have been shown to protect the cardiovascular system from damaging effects of lipid peroxidation. Thus, we concluded that applying high levels of P nutrition may increase the health functionality of apples in some, but not all, weather conditions.

Tomatoes

We grew tomatoes in soils testing rich in P (30 to 50 ppm Olsen-P) at Cambridge, Ontario, in three seasons from 2000 to 2002. Treatments in all years included soil-applied P fertilizer at 45 and 150 lb P_2O_5/A, and foliar treatments supplying 16 lb P_2O_5/A in addition to the soil-applied rate of 45 lb P_2O_5/A. In two of the three years, two additional treatments included rates of zero and 260 lb P_2O_5/A.

Lycopene levels responded differently to added P each year (**Table 1**). In 2000, the year with the highest stress and poorest tomatoes, lycopene increased as the P_2O_5 rate increased to 150 lb/A but then declined at the highest rate. In 2001, the highest rate was omitted, but lycopene increased as applied P increased. In 2002, the highest yielding year, there was no response to applied P. In all years, foliar P produced intermediate levels of lycopene.

Table 1. Applying P influenced lycopene levels in tomato juice.

P applied, lb P_2O_5/A	Lycopene, ppm 2000	2001	2002
0		180 b	182 a
45	61 b	197 ab	180 a
150	77 a	221 a	173 a
260	61 b		161 a
16 (foliar)	69 ab	211 a	176 a

Values followed by the same letter within a column do not differ significantly (p=0.05).

We also measured other quality parameters in the juice and processed sauce, including Brix, acidity, vitamin C, viscosity, and flavor volatiles. Most of these were not affected significantly by applied P, but Brix followed a pattern similar to lycopene. We also found that applied P increased the levels of several anti-oxidant enzymes in 2001. We are continuing research on these enzymes.

Overall, results indicate that even in soils with high P fertility, optimum levels of P are important for tomato quality, but vary depending on the growing season. Further research may identify specific combinations of soil and foliar applications of nutrients that can optimize quality specific to the growing conditions of a particular year.

Discussion

Regulation of nutrient management appears likely to place limits on the use of P fertilizer in the near future. For many horticultural crops, growers apply considerably more P than is removed by the crop. Formal recommendations are often based on scant information and few field calibration trials. Our results and others indicate that, in general, high levels of P are necessary for good quality in fruits and vegetables, but also that excessive applications can potentially limit quality. Since both human health and risk of environmental contamination are at stake, strong research efforts to improve prediction of optimum rates of P application are justified.

The soils in these studies on apples and tomatoes represented the typical high fertility levels that most of today's growers use. If even on these soils P impacts the levels of phytochemicals, its role in soils of lower fertility is undoubtedly stronger.

Growing interest in organic farming practices is driving some producers to manage with lower inputs of soluble mineral fertilizers. A recent study in California reported higher levels of phenolics in blackberries, strawberries, and sweet corn—and higher levels of vitamin C in the latter two

(continued on page 11)

OKLAHOMA

In-Season Fertilizer Nitrogen Rates Using Predicted Yield Potential and the Response Index

By W.R. Raun, G.V. Johnson, J.B. Solie, M.L. Stone, K.L. Martin, and K.W. Freeman

Refining in-season fertilizer nitrogen (N) rates through the use of optical sensor technology has been a major research priority at Oklahoma State University (OSU). Basing mid-season N fertilizer rates on predicted yield potential and a response index have increased N use efficiency (NUE) by over 15% in winter wheat when compared to conventional methods.

From the early 1950s to the early 1970s, increased food production was a priority in agricultural areas around the world. During this time period, the largest increase in the use of agricultural inputs was N fertilizer, because it had the largest impact on yield. Since the early '60s, the increase in fertilizer N consumption has continued, becoming somewhat stable over the past 10 years. Although fertilizer N consumption and cereal grain production have both increased over the last 5 decades, contamination of surface water and groundwater supplies continues to be a concern in some areas. According to analysis by scientists at OSU, the efficiency at which fertilizer N is used has remained at 33% worldwide.

Current strategies for winter wheat recommend that farmers apply about 2 lb N/A for every bushel of expected wheat grain yield, subtracting the amount of NO_3-N in the surface soil (0 to 6 in.). When grain yield goals are applied using this strategy, the risk of predicting the environment (good or bad year) is placed on the producer, especially when farmers take the risk of applying all N preplant.

Why Should N Rates Be Based on Predicted Yield?

Optical sensor technology is helping Oklahoma researchers refine in-season fertilizer N rates for winter wheat, based on projected N removal. The applicator shown here is a field scale machine, 60 ft. wide.

In the last century, yield goals have provided methods for determining pre-plant fertilizer N rates in cereal production. This makes sense, because at a given level of yield for a specific crop, nutrient removal can be estimated based on concentrations in the grain. Once expected removal amounts are known, mid-season application rates are determined by dividing removal by the projected use efficiency. Similarly, known quantities of phosphorus (P), potassium (K), sulfur (S), and other nutrients within particular cereal grain crops have been published. Based on these concentrations, mid-season nutrient rates could be determined at specific foliar nutrient application efficiencies.

The algorithm for refining mid-season fertilizer N rates has been divided into components that follow. Our approach is based on the ability to predict yield potential since this will ultimately determine the total amount of a given nutrient that will be removed in each crop.

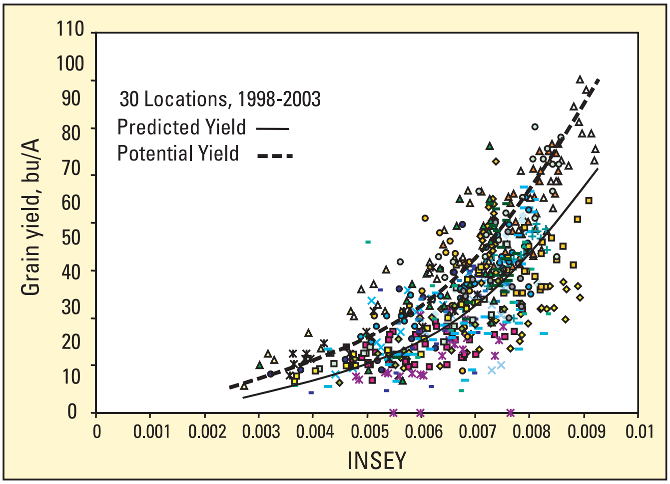


Figure 1. Relationship between observed wheat grain yield and the In-Season Estimated Yield (INSEY) determined by dividing NDVI by the number of days from planting to sensing (days where growth was possible, or GDD>0) at 30 locations from 1998 to 2003.

1. Estimate of Yield Potential

Work at OSU has shown that early-season Normalized Difference Vegetation Index (NDVI) optical sensor readings of winter wheat were highly correlated with total plant biomass. The effect of timing (i.e., the number of days of active plant growth prior to sensing) can be minimized by dividing NDVI readings by the number of days from planting to sensing for those days where growing degree days... ($GDD=[(T_{min}+T_{max})/2]-40°F$) ...are more than 0. In essence, the index, or In-Season Estimated Yield (INSEY), was an estimate of biomass produced per day when growth was possible. We have shown that optical sensor readings can be collected once, anytime within Feekes growth stages 4 and 6, and that INSEY was an excellent predictor of yield (grain or forage). This work was recently updated to include 30 locations over a 6-year period from 1998 to 2003 (**Figure 1**).

What is striking from this research is that planting dates ranged from September 24 to December 1, and sensing dates ranged from February 10 to April 23, yet yield prediction (solid line) remained reasonably good. The results indicate that for winter wheat, biomass produced per day is an excellent predictor of grain yield. Furthermore, over this 6-year period, five different varieties (Tonkawa, 2163, Custer, 2137, and Jagger) were included. It is noteworthy to find such a good relationship with final grain yield simply because so many uncontrolled variables from planting to sensing have the potential to adversely affect this relationship.

Because of the importance of yield potential for determining N application rates, we must expand on the concept. To correctly predict the potential yield, the model should be fitted to yields unaffected by adverse conditions from sensing to maturity. This curve more realistically represents the yield potential achievable in rainfed winter wheat, considering that post sensing stresses (moisture, disease, etc.) from February to July can lower "observed yields." We currently add 1 standard deviation to the predicted yield equation in order to better reflect actual yield potential **(Figure 1)**.

Added work has shown that it is possible to establish reliable yield potential prediction from only 2 years of field data, provided that enough sites were evaluated within this time period.

2. Estimating the Responsiveness to Applied N

Identifying the specific yield potential does not necessarily translate directly to a recommendation for N. Determining the extent to which the crop will respond to

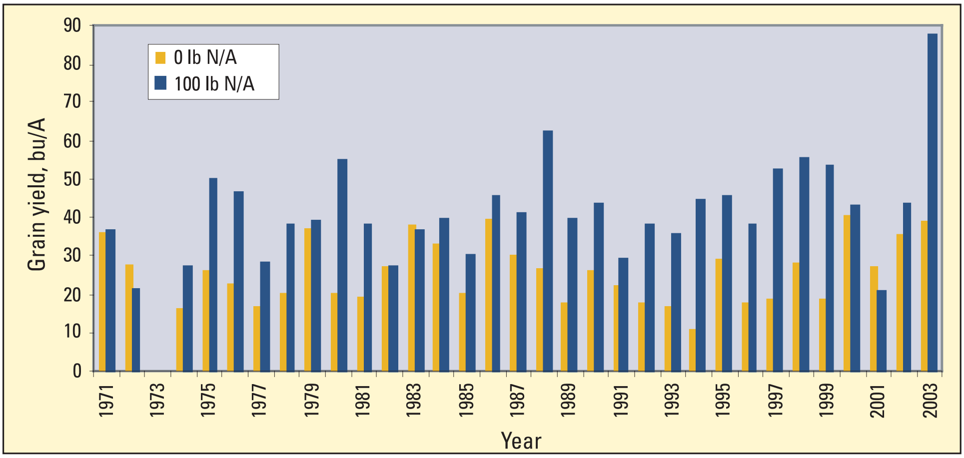


Figure 2. Average winter wheat grain yield from 1971 to 2003 from treatments receiving 100 lb N/A annually and no fertilizer N (0 lb N/A), long-term experiment #502, Lahoma, Oklahoma. Both P and K were applied each year to both treatments at rates of 41 lb P_2O_5/A and 60 lb K_2O/A, respectively.

additional N is equally important. The response index (RI_{NDVI}) is computed by taking average NDVI from a strip within farmer fields where N has been applied at non-limiting, but not excessive amounts (N Rich Strip) and dividing by the NDVI in the farmer check plot (common farmer practice). This fertilizer index was developed following comprehensive work at demonstrating that the response to applied N in the same field is extremely variable from one year to the next, and independent of whether or not previous year yields were high or low. We studied grain yield response to applied N in a long-term replicated experiment where the same rates were applied to the same plots each year for over 30 years (**Figure 2**).

Because the response to N fertilizer depends on the supply of non-fertilizer N (mineralized from soil organic matter, deposited in the rainfall, etc.) in any given year, N management strategies that include a reliable mid-season predictor of RI_{NDVI} should dramatically improve NUE in cereal production. This same work noted that the RI values changed considerably when collected from the same plots that had been managed the same way for 30 years. This is attributed to the striking differences in rainfall and temperature from one year to the next and associated crop need, which influenced how much non-fertilizer N was used by the crop. Furthermore, the in-season RI_{NDVI} was found to be an excellent predictor of the actual responsiveness to applied fertilizer N when measured at harvest.

3. Integrating Yield Potential and the Response Index

For the Nitrogen Fertilization Optimization Algorithm (NFOA) currently being used, yield potential with no added N fertilization (YP_0) is predicted using NDVI readings divided by the number of days from planting to sensing. The yield obtainable with added N fertilization (YP_N) is determined by multiplying YP_0 by RI_{NDVI}. The fertilizer rate to be applied is determined by computing N uptake in the grain at YP_N minus N uptake in the grain at YP_0 divided by an expected use efficiency factor (between 0.5 and 0.7).

Grain N uptake for YP_0 and YP_N is determined by multiplying the respective predicted grain yield times a known percent N value in each grain or forage crop for each specific region. For winter wheat in the central Great Plains, the percent N in the grain averages 2.39% for winter wheat, 1.18% for corn grain, and 2.45% for spring wheat. This same concept could apply for different nutrients and different crops. Although factors other than N can influence yield potential, the value of this approach is that N fertilizer will ultimately be applied based on the specific yield potential of each 4.3 ft^2 area and the potential responsiveness to N for each particular field.

The need to sense biological properties on a small scale was established at OSU. Current work is focusing on the evaluation of statistical properties within each 4.3 ft^2 area, understanding that the nutrient variability within this area will likely be minimal. Fortunately, the sensors developed and used in all of the OSU sensor research are capable of collecting enough data within each 4.3 ft^2 to calculate meaningful statistical estimates. Now, more importantly, these statistical estimates combined with average NDVI have been shown to be useful for mid-season yield prediction and subsequent fertilizer N rate recommendations. Using the algorithm reported earlier, we showed that winter wheat NUE was improved by more than 15% when N fertilization was based on optically sensed INSEY and the RI_{NDVI} compared to traditional practices at uniform N rates. We are not aware of any biological basis to suggest that this approach would not be suitable in other cereal crops.

The sufficiency approach that is being evaluated in the Corn Belt today and that applies fertilizer to all plots when found to be below a theoretical maximum (<95%) does not take into account yield level, or yield potential, and more importantly the quantitative responsiveness to applied N inherent in the response index.

There is ample evidence that wheat potential yield can be reliably predicted from in-season sensor measurements. Basing fertilizer N needs on projected removal (dry matter yield times known concentrations in the grain) should be encouraged since removal amounts are known to vary temporally and spatially. BC

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Phytochemicals...(continued from page 7)

crops—when managed with practices other than "conventional". However, in both of the "non-conventional" management systems evaluated, the applied nutrients included large amounts of P. Unfortunately the level of P fertilization in the "conventional" system was unknown. It is possible that the results obtained—attributed to differences among systems in pests and pesticide use—were in fact caused by differences in nutrient levels. More attention to nutrient levels is necessary when making system comparisons. BC

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Financial support for this research was provided by: PPI/PPIC; Phosyn PLC, U.K.; H.J. Heinz Company of Canada Ltd.; and the CanAdapt Program of the Agricultural Adaptation Council.

Detecting Phosphorus with Plasma Emission Spectroscopy May Require Unique Field Calibration Data

By Antonio P. Mallarino and T. Scott Murrell

Using inductively coupled plasma emission spectroscopy (ICP) to measure phosphorus (P) in the Mehlich 3 (M3) extractant produces higher test results than the traditional colorimetric procedure (COL), requiring the creation of new soil test interpretation categories. The M3-ICP procedure should be considered a different soil P test than M3-COL. Failing to do so could result in large recommendation errors and significant underestimation of supplemental P needs.

In a soil testing laboratory, one of the first steps in generating a soil test P value is to get a portion of the total soil P into solution that is proportional to the soil P available to plants. To do this, a small measure of soil from a submitted sample is mixed with a solution of different chemicals, termed an extractant. In the Midwestern U.S., three extractants are commonly used for P: Bray P-1, Olsen, and M3. Mehlich 3 is gaining popularity among laboratories, because it can be used to extract more elements than just P and it produces reliable results across a wider range of pH levels than does Bray P-1.

Once P is extracted, the amount dissolved must be measured. There are two commonly used techniques for doing this: 1) COL, and 2) ICP. In the past, soil testing laboratories used only the molecular absorbance method. Recently, however, many laboratories have begun using ICP. This article briefly describes these detection methods and how they influence soil test interpretations appropriate for the M3 extractant.

COL

A standard P detection method for many soil P extractants is COL. After a soil test extractant has dissolved P from a soil sample, the solution is filtered to obtain a clear solution. More chemicals are then added that react with dissolved orthophosphate P ($H_2PO_4^-$ or HPO_4^{2-}) and turn the solution blue. The blue solution is then placed in a clear cell in a spectrophotometer. This instrument measures the absorption of energy by P molecules (**Figure 1a**). Light of a specific wavelength, coming from a radiation source, is directed at the sample. Some of the radiation is absorbed by the molecules in the sample. Radiation not absorbed passes through the sample and is captured by a detector. As P concentration in the sample increases, more radiation is absorbed, reducing the intensity of the radiation transmitted to the detector. Consequently, measuring the intensity of transmitted radiation allows P

The blue solution is characteristic of the traditional colorimetric procedure for P detection.

Note: In this article, the classic M3 colorimetric procedure is referred to as M3-COL, while a M3 procedure that uses ICP is referred to as M3-ICP.

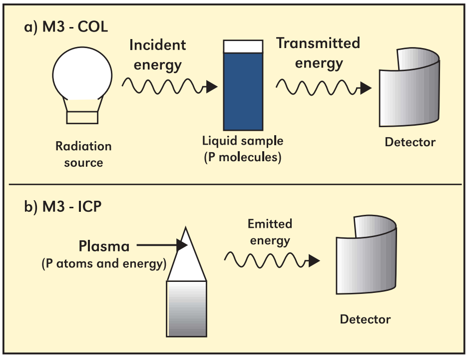


Figure 1. Simplified diagrams show how P is quantified in the Mehlich 3 extractant using a) the colorimetric procedure (M3-COL), and b) inductively coupled plasma emission spectroscopy (M3-ICP).

concentration to be quantified.

ICP

Another means of measuring P in any extractant solution is ICP. In this method, the sample is heated to such an extreme temperature that all molecules decompose into atoms to form a gas. The source of extreme heat is an inductively coupled plasma (**Figure 1b**). The high energy plasma excites electrons in the P atom to a higher energy state. This excited state doesn't last long, and soon the electrons return to their original energy states. During this return, energy is emitted from the sample and hits a detector. The more P that is in the sample, the greater the emitted energy detected. In this method, detected energy comes from all P compounds, not just orthophosphate P.

What the Procedures Measure

These two methods do not measure the same things. In M3-COL, only orthophosphate P is measured. Most of the P extracted by soil tests is in the orthophosphate form, but there are also other P compounds that may be present, such as simple organic P compounds and P associated with very small soil particles that sometimes pass filters. These additional compounds are not detected in M3-COL, but can be detected in M3-ICP. **Consequently, P measured using an M3-ICP tends to be greater than P measured by M3-COL, even using the same soil sample or extracted solution.**

Because the M3 extractant measures several other elements also, some laboratories use ICP for measuring P in a M3 extractant, but use COL when measuring P from Bray P-1 or Olsen extractants. As of 2003, more than 60% of the soil testing labs in the North American Proficiency Testing Program were requesting proficiency testing for M3-ICP, although fewer labs use M3-ICP for testing farmers' samples.

Need for Field Calibration Experiments

For any soil test method to have meaning, values generated must be calibrated to crop yield response in the field. With M3-ICP and M3-COL methods measuring different things, many wondered if different field calibration data were needed for each procedure. To answer this question, field calibration research for corn was conducted across 78 site-years. These sites represented 17 soil series in which row crop production predominates in Iowa. Thirty-one trials evaluated four P fertilization rates for corn managed with plow and/or disk tillage; 13 trials evaluated three P fertilization rates applied either broadcast or banded for no-till corn; and 15 trials evaluated three P rates applied either broadcast or banded for ridge-till corn. Corn grain yield and soil samples were collected in each site-year.

Corn grain yield data were expressed as relative responses to P. Relative response was calculated for each site-year by dividing the average yield of the control plots (no P applied) by the average yield of the treatment with the highest P rate. This fraction was then multiplied by 100 to express relative response as a percentage.

Two sub-samples were taken from each soil sample. Each sub-sample was mixed with the M3 extractant. One aliquot of each sub-sample was put through the M3-COL procedure and a second aliquot was subjected to M3-ICP analysis.

The average soil P measured by M3-ICP and M3-COL across all sites was 31 and 19 parts per million (ppm), respectively. These averages show that for the same samples, M3-ICP measured more P than M3-COL. **Figure 2** shows the relationship between P measured by M3-ICP and M3-COL for all site-years. The high r^2 value indicates that both analyses are well correlated and highly significant. If both procedures measured the same amount of P, then most of the points would fall along the 1:1 line. However, most points fall above this line, demonstrating the higher quantity of P detected by M3-ICP across the range of soil test P levels.

Figure 3 shows corn grain calibration data from the field experiments. Grain yields across all site-years ranged from 87 to 210 bu/A. **Figures 3a and 3b** show the relationships between relative corn grain yield responses to applied P and P measured by either M3-COL or M3-ICP, respectively.

In both graphs, the optimum ranges are defined as soil test levels most profitable to maintain over time with regular P applications.

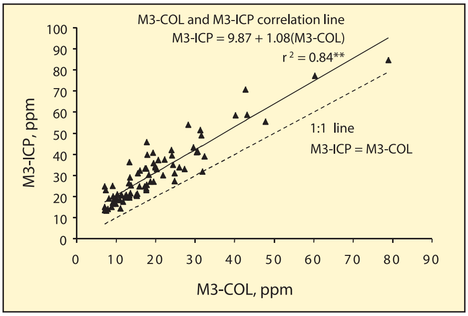


Figure 2. Correlation between M3 P measured by the colorimetric procedure (M3-COL) and inductively coupled plasma emission spectroscopy (M3-ICP).

These results, combined with crop response and economic models, led to the formation of new soil test interpretation ranges for the M3-ICP test, shown in **Table 1**. This table shows that higher soil test P values are used to define wider soil test categories when M3-ICP is used.

The categorization of high and low subsoil P levels is based on previous research showing that lower P levels are needed at the surface when subsoil P levels are higher. Recommendations in **Table 1** are based on soil samples taken to a 6 in. depth.

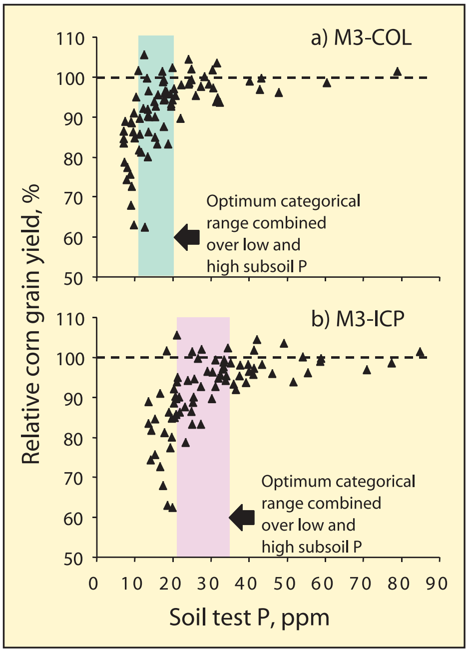


Figure 3. Relationship between relative yield response of corn grain and M3 P measured by the colorimetric procedure (M3-COL) and inductively coupled plasma emission spectroscopy (M3-ICP).

These new ranges took effect in 2002 and were published in the Iowa State University Cooperative Extension Bulletin PM 1688 entitled “A General Guide for Crop Nutrient and Limestone Recommendations in Iowa.” It may be downloaded at

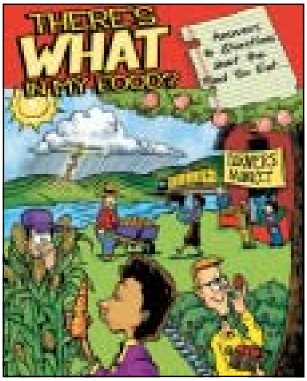
Table 1. Updated Iowa State University soil test P interpretation classes for P measured by M3-COL and M3-ICP.

	Soil test category				
Soil test	Very low	Low	Optimum	High	Very high
			ppm		
			Low subsoil P		
M3-COL	0-8	9-15	16-20	21-30	31+
M3-ICP	0-15	16-25	26-35	36-45	46+
			High subsoil P		
M3-COL	0-5	6-10	11-15	16-20	21+
M3-ICP	0-10	11-20	21-30	31-40	41+

New Publication Offers Insight about Food Quality/Safety Concerns

While consumers today have ready access to perhaps the most nutritious, safe, and affordable food products in history, many continue to have doubts and questions about food safety, quality, and other issues.

A new publication from PPI/PPIC and the Foundation for Agronomic Research (FAR) addresses this situation. The booklet is titled *There's WHAT in My Food?* Presented primarily through a question/answer format, the 24-page publication includes colorful illustrations in a friendly style to appeal especially to non-farm audiences.



For those involved in agriculture and fertilizer industry work, this publication can be another useful and effective tool in providing a fresh, positive message to consumers.

The booklet is available for purchase at $2.00 per copy (plus shipping), with discounts for larger quantities. Some sample pages of the booklet may be viewed as PDF files on the Institute's website through this link: www.ppi-ppic.org/food. An order form is also available there as a PDF file.

For additional information or to order, contact: Circulation Department, PPI, 655 Engineering Drive, Suite 110, Norcross, GA 30092-2837. Phone: (770) 825-8082; fax (770) 448-0439.

>www.extension.iastate.edu/Publications/PM1688.pdf<.

Although not discussed in this article, differences between M3-COL and M3-ICP for soybeans were analogous to those discussed for corn grain.

Summary

Using M3-ICP resulted in higher soil test levels than those produced with M3-COL. The additional P measured with the M3-ICP test varied greatly across Iowa soils and cannot be accurately predicted from results of the M3-COL test. This required that new field calibration data be collected for the M3-ICP test. Results from field trials showed that when M3-ICP was used to measure P concentration in the M3 extractant, new soil test interpretation classes were needed. Laboratories should clearly inform their clients of which P detection method is being used with the M3 extractant.

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NEW JERSEY

Greensand as a Soil Amendment

By J.R. Heckman and J.C.F. Tedrow

The benefits in plant growth sometimes observed following greensand application are likely not due to nutritional benefits, but from changes in soil physical properties.

Greensand is composed largely of glauconite, a unique mineral that occurs as a natural geologic deposit that stretches as a belt across New Jersey from Monmouth County to Salem County. Greensand also occurs in parts of Delaware, Maryland, and Virginia. Although there are several theories of origin, greensand is generally thought to have formed in shallow marine seas near the interface of water and land.

Since the late 1800s, millions of tons of greensand have been spread over soils in New Jersey and other parts of the U.S. For this reason, greensand may occur today in many soils where it was not originally present. The presence of greensand may still be benefiting crops by improving the soil's ability to hold water and store nutrients. In the early part of the 20th century, there were about 80 open pit mines in New Jersey where greensand was mined. There are only a few of these mines operating today. The photo at left shows a view of a modern mine.

Modern greensand mining operation in Gloucester County, New Jersey.

The olive green-colored glauconite mineral in greensand is unusual. Unlike most types of clay, which are very fine, glauconite often exists as sand-sized pellets, as shown in the photo below. Glauconite does not behave like typical sand, since it is a mica-like complex composed mostly of muscovite- and illite-like clay minerals, containing many micro-pores. Also, unlike a true sand, the micro-pores in greensand contribute to soil water-holding capacity. In this way, it differs from true sands, which are composed of minerals such as quartz and feldspars. Greensands typically have a high cation exchange capacity (ranging from 20 to 30 cmol/kg). Addition of greensand to sandy soils enhances the ability of the soil to store exchangeable nutrients such as calcium (Ca), magnesium (Mg), potassium (K), and micronutrients. These desirable physical and chemical properties may explain how greensand can be useful as a soil amendment.

Pure glauconite generally contains up to 8% K_2O and small amounts of phosphorus (P), Ca, and trace elements. However, since greensand contains other non-

Glauconite pellets from the Hornerstown formation (photo by R. Holzer).

beneficial constituents as well as glauconite, the K content of commercial products generally falls well below this value (from 0.1 to 7% K_2O).

The issue of K availability from greensand has been studied since the 19th century, when positive crop responses were occasionally observed following application. Almost all investigators have concluded that greensand has very little value as a nutrient source. Greensand is sometimes recommended as a natural K source for organic agriculture. Recent research suggests that greensand benefits may be a result of changes in soil physical properties and not improved plant nutrition.

A field trial near New Brunswick, New Jersey, evaluated the response of potatoes to various rates of greensand applied in the row at time of planting with the seed pieces (**see photo**). The study was conducted on a Sassafras sandy loam soil that had relatively low organic matter content and poor physical condition as a result of many years of continuous cropping to vegetables. Thus, this field site afforded the opportunity for greensand to express soil-conditioning attributes. Potato tuber yields were on average 16% higher where the greensand treatments were applied (**Table 1**). The crop was uniformly fertilized with 108, 7, and 134 lb/A of nitrogen (N), P_2O_5, and K_2O, respectively. Tissue analysis revealed no differences in nutrient concentrations in the potato leaves. Thus, the positive yield response was not likely related to an influence of greensand on plant nutrition, but improved soil properties.

Greensand applied in the seed furrow before planting potatoes.

Table 1. Yukon Gold potato tuber yield and specific gravity in response to greensand application in the seed furrow prior to planting in 2003.

Greensand rate, lb/A	Tuber yield, cwt/A	Tuber specific gravity
0	91	1.063
125	105	1.061
250	107	1.063
500	105	1.063
Significance* (check vs. others)	0.04	NS

*The check was significantly different than the treatments @ p=0.04.

Conclusion

In general, greensand should be considered more valuable as a soil conditioner than as a fertilizer. Micro-pore spaces within glauconite can enable greensand-amended soils to have improved water-holding capacity and increased ability to store and retain nutrients. These changes may or may not result in a positive plant response, depending on the specific soil. Although organic matter additions may also improve soil water holding capacity and nutrient retention, the changes resulting from adding greensand to soil are permanent. BC

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Additional information regarding greensand is available from: J.C.F. Tedrow, 2002. Greensand and Greensand Soils of New Jersey: A Review. Rutgers Cooperative Extension, Bulletin E279. Website: >www.rce.rutgers.edu/pubs/pdfs/e279<.

WESTERN CANADA

Cropping System Impact on Phosphorus Management of Flax

By C.A. Grant, M. Monreal, D.D. Derksen, R.B. Irvine, D. McLaren, R.M. Mohr, and J.J. Schoenau

The phosphorus (P) nutrition of flax was found to be influenced most by preceding crop in rotation, while tillage system and P fertilizer management had only minor impact.

Reduced tillage systems are becoming increasingly popular on the Canadian prairies. They have been shown to conserve soil moisture, increase crop yield potential, and improve soil quality, while reducing time, labor, and equipment costs in farming operations. Reducing tillage also has important implications for nutrient management. It impacts soil moisture relations, the distribution of nutrients in the profile, surface accumulation of crop residues, and changes the type and activity of soil micro-organisms compared to conventional tillage. Ultimately, this directly influences nutrient availability and fertilizer management decisions.

Phosphorus fertilization of flax can be problematic because flax is very sensitive to seed-placed applications of monoammonium phosphate (MAP). Broadcast application has not been effective in correcting P deficiencies. Pre-plant or side band applications of P fertilizer to flax have low efficiency unless they are positioned within 1 to 2 in. of the seed-row. Therefore, unless a producer has access to seeding equipment capable of side-banding, P fertilization of flax is frequently ineffective. This has caused some producers to skip P application in flax and increase the P supply in the preceding crops, in an attempt to increase residual P for use by the subsequent flax crop in rotation.

Flax is a highly mycorrhizal crop. It is possible mycorrhizal associations could be responsible for part of the positive response that flax shows in no-till systems, and for the limited fertilizer P response observed in field studies. If so, P fertility requirements in flax could be greatly affected by tillage system (no-till preserves mycorrhizae) and whether the preceding crop was mycorrhizal or not (wheat vs. canola, respectively).

We asked the question: Could P fertilization be reduced or eliminated for flax by using no-till, adding extra P to the previous crop in rotation, and using a mycorrhizal crop before flax?

This field study was established at two locations approximately 4 miles apart, on the same clay loam soil type (Udic Boroll) in southern Manitoba. The Research Centre location was in conventional tillage…average pH, 7.8; average organic matter, 5.0%; initial soil test P (Olsen), 10 to 15 parts per million (ppm). The Zero-till Farm was an established (6 years) no-till field…average pH, 7.7; average organic

A strategy to maintain soil P levels through the rotation by targeting applications to more responsive crops may be more cost effective than application of P to flax, unless P supply is extremely depleted.

matter, 5.0%; initial soil test P (Olsen) 10-12 ppm. In year one of the study, canola and spring wheat were seeded using conventional tillage (CT) and no-till (NT), and fertilized with either 0, 22, or 44 lb P_2O_5/A side-banded at seeding. After harvest of the canola and wheat, the stubble in the CT plots was tilled. In year two, the flax was seeded into both stubble and tilled plots, with fertilizer P side banded at either 0 or 44 lb P_2O_5/A (**Table 1**). This 2-year sequence was repeated three times at each location (1999-2000, 2000-2001 and 2001-2002). Plant roots were evaluated for mycorrhizal association at five weeks of growth and seed yield was collected at crop maturity.

Mycorrhizal incidence in 2001 was greater for flax following wheat than flax following canola at both locations, although the difference was larger at the Research Centre than the Zero-till Farm (**Table 1**). This supports previous research which identified canola as a non-mycorrhizal crop, reducing association with crops seeded after canola in rotation. Association was greater with NT than CT at the Zero-till Farm after both of the preceding crops and at the Research Centre after canola. There was no effect of tillage system at the Research Centre after wheat. The level of mycorrhizal association was very high after wheat at the Research Centre, so it is possible that the tillage system had no effect due to the high degree of association present in wheat stubble. Association was reduced at both locations by side-banded P fertilization in the flax, with an interesting tendency (p=0.06) for mycorrhizal association to increase with residual P at the Research Centre and decrease with residual P at the Zero-till Farm. These mycorrhizal incidence results, from a single year of sampling, indicate a high degree of variability associated with preceding crop, fertilizer rate, and tillage practice. Similar patterns in mycorrhizal responses occurred in 2002, although

Table 1. Effect of P fertilizer application to current year flax, previous crop type and P fertilizer management, and tillage system on mycorrhiza incidence and flax seed yield.

P in flax	P in previous crop	Research Centre				Zero-till Farm			
		Canola		Wheat		Canola		Wheat	
		CT	NT	CT	NT	CT	NT	CT	NT
lb P_2O_5/A		Mycorrhiza incidence[1], % of root area covered							
0	0	4.65	5.80	9.40	8.00	3.01	6.13	3.86	8.23
0	22	4.00	6.85	9.31	9.68	3.19	5.47	3.42	4.01
0	44	5.65	11.43	11.38	10.63	3.25	3.50	2.33	7.79
22	0	3.83	4.52	11.04	6.33	5.14	4.30	2.12	5.64
22	22	5.41	5.85	7.19	12.68	3.17	2.70	1.52	4.33
22	44	6.40	4.84	8.10	8.46	1.90	4.42	2.18	3.69
Tillage mean		4.99	6.55	9.40	9.30	3.28	4.42	2.57	5.62
Preceding crop mean						5.77	9.35	3.85	4.09
lb P_2O_5/A		Seed yield[2], bu/A							
0	0	24.9	25.1	25.1	28.4	25.5	22.1	30.1	27.8
0	22	23.9	27.1	26.6	26.7	24.0	22.2	29.0	29.5
0	44	24.4	24.6	26.8	27.9	26.4	22.2	27.4	28.3
22	0	24.1	25.4	27.0	27.2	27.2	21.3	29.6	28.8
22	22	25.3	25.8	29.1	28.7	23.8	23.9	30.8	25.7
22	44	25.7	25.0	28.9	28.4	23.9	21.5	31.2	29.1
Tillage mean		24.7	25.5	27.3	27.9	25.1	22.2	29.7	28.2
Preceding crop mean						25.1	27.6	23.7	28.9

[1] Mycorrhiza incidence for 2001 flax crop only.

[2] Grain yield response an average of 3 years, 2000-2002.

mycorrhizal association was more consistently depressed with residual P than in 2001.

There were few significant influences of the management variables evaluated in this study on the seed yield of flax. Preceding crop was found to have the greatest influence on flax seed yield at both sites (p=0.0001), with mean seed yield averaging 10% and 22% higher after wheat than canola at the Research Centre and Zero-till Farm sites, respectively (Table 1). The effect may be due to a number of factors, including some degree of allelopathy from canola residue, early season competition from volunteer canola plants, and restriction in mycorrhizal colonization after canola.

There was a tendency (p=0.07) for seed yields at the Research Centre site to be higher when P fertilizer was applied to flax, although the difference was small. At the Zero-till Farm site P application had no effect on flax seed yield. Flax yield did not seem to be effected by tillage system in the study. At the Zero-till Farm site, flax seed yield tended (p=0.08) to be higher after CT than NT. These results support previous research on the Canadian prairies which found that flax is well adapted to no-till seeding systems.

Based on the interim information from this study, it appears that P nutrition of flax can be influenced by tillage system, preceding crop, residual P from fertilization of preceding crops and by side-banded P application in the flax. Therefore, it may be possible to select different P management strategies to optimize flax P nutrition and seed yield, depending on the cropping system and crop rotation used and the equipment available. The overall benefit from either applying P fertilizer to the flax crop or increasing P application in the preceding crop to benefit the following flax crop was minimal.

The P status of the soils in this study was low to moderate and P fertilizer responses occurred in other crops. Phosphorus fertilization of flax may be more beneficial on soils where P supply is extremely depleted. However, with moderate deficiencies, the benefit is likely to be low. A P management strategy to maintain P through the rotation by targeting applications to more responsive crops would possibly be more cost-effective than application of P to flax. If soil P levels are not depleted, increased applications of P to preceding crops will likely not improve the yield of the following flax crop. BC

Drs. Grant (e-mail: cgrant@agr.gc.ca), Derksen, Irvine, McLaren, Mohr, and Monreal are with the Brandon Research Centre, Agriculture and Agri-Food Canada, Brandon, Manitoba. Dr. Schoenau is with the Department of Soil Science, University of Saskatchewan, Saskatoon, Saskatchewan.

TOOLBOX

PKalc Software Checks Nutrient Balance

"Toolbox" is a feature on the PPI/PPIC website which holds free downloadable software tools for improved nutrient management. One useful tool is called PKalc (v.1.13), a simple balance calculator which helps users determine if phosphorus and potassium nutrient additions are keeping up with removal by crops.

PKalc and other programs can be accessed for free at:

>**www.ppi-ppic.org/toolbox**< BC

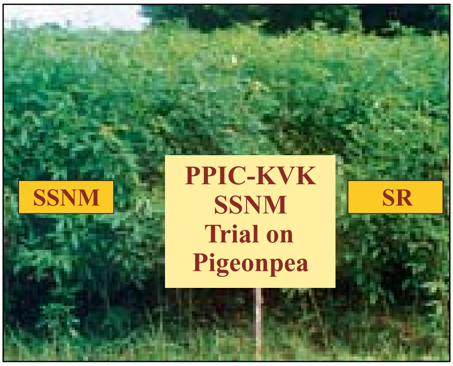
Site-Specific Nutrient Management for Optimal Foodgrain Production in Haryana

By K.S. Yadav and Hira Nand

Cropping systems governed by either generalized state soil testing recommendation systems or common farmer practice are incapable of maximum economic yield. In this study, it is evident that inadequate nutrient use is severly limiting pearl millet and pigeonpea production in Haryana State.

A five-fold increase in foodgrain production in Haryana State during the last 35 years combined with inadequate and unbalanced nutrient supply has led to continued and accelerated soil nutrient depletion of all essential plant nutrients. Farmers in Haryana apply generalized quantities of nitrogen (N), phosphorus (P), and zinc (Zn) in foodgrain crops, and as a consequence, deficiencies of P, potassium (K), sulfur (S), iron (Fe), manganese (Mn), and copper (Cu), and boron (B) are increasing. Deficiencies of S and Fe have become especially widespread during the last decade in fields growing pearl millet, sugarcane, wheat, and legumes. The desire for sustained productivity in these important soils places an urgent need to arrest this trend.

Pearl millet and pigeonpea crops presently occupy 586,000 ha and 16,000 ha, respectively, in Haryana, and corresponding productivity for these two crops is quite low at 1.42 t/ha and 0.81 t/ha. Opportunity for improvement exists through better nutrient management coupled with other best management practices. A research project was initiated to study the effect of site-specific nutrient management (SSNM) on crop yield and profit while demonstrating the drawbacks of relying on common farmer practice or even state fertilizer recommendations.



Site-specific nutrient management (SSNM) can increase productivity of pigeonpea.

Field experiments were conducted during 2001-02 in farmers' fields in the village of Tikli in Gurgaon District. Soils were sandy loam, alkaline in reaction, low in organic matter, with cation exchange capacities varying between 10 to 12 $\text{cmol}_{(+)}$/kg. Soils were generally deficient in available N, P, K, S, Zn, Fe, and Mn. Pigeonpea var. UPAS-120 was sown in the last week of June while pearl millet hybrid var. HHB-67 was sown in first week of July. Ten nutrient treatments were applied as a randomized block design (RBD) with four replications (**Table 1 and 2**). In pigeonpea, all nutrient quantities were applied as a basal dressing. In pearl millet, N was applied as two splits divided between sowing and a first mid-season irrigation. Crops were irrigated as required and weed growth was controlled. Pigeonpea was harvested in November and pearl millet in September. Data for grain and straw/stover yields were recorded on an air-dry basis. Economic analysis included treatment and general cultivation costs.

Table 1. Effect of fertilizer treatments on pigeonpea grain and stover yield and net profits, Haryana.

Treatments	Grain yield	Stover yield	Net profits[2],
	- - - - - t/ha- - - - -		US$/ha
1. N_{20} P_{90} K_{125} plus S+Micros'[1]	2.03	4.08	354
2. N_{20} P_{60} K_{125} plus S+Micros'	2.01	3.90	355
3. N_{20} P_{30} K_{125} plus S+Micros'	1.89	3.85	338
4. N_{20} P_{0} K_{125} plus S+Micros'	1.84	3.55	325
5. N_{20} P_{60} $K_{62.5}$ plus S+Micros'	1.81	3.80	310
6. N_{20} P_{60} K_{187} plus S+Micros'	2.02	4.10	271
7. N_{20} P_{60} K_{0} plus S+Micros'	1.77	3.35	300
8. N_{20} P_{60} K_{125}	1.86	3.70	331
9. N_{20} P_{40} (State recommendation)	1.49	3.16	231
10. N_{20} P_{60} (Farmers' practice)	1.66	3.12	285
Critical difference (CD) = 5%	0.18	0.29	

[1] Includes 30 kg S/ha, 5 kg Zn/ha, 3.8 kg Fe/ha, and 3 kg Mn/ha. Urea, diammonium phosphate, and potassium chloride were the N, P, and K sources, while Zn, Fe, Mn, and Cu were supplied via respective sulfate sources.

[2] 1 US$ = 45.28 Indian Rupees.

Pigeonpea Response

The complete treatment supplying 20-60-125 kg N-P_2O_5-K_2O/ha as well as a S+micronutrient package provided the best result by producing the highest profit of US$355/ha with a grain yield of 2.01 t/ha (**Table 1**). Treatments based on the state recommendation (SR) and common farmer practice (FP) both omitted K fertilizer and returned significantly less grain yields, i.e. 1.49 t/ha (-26%) and 1.66 t/ha (-17%), respectively. Corresponding net returns were US$231/ha (-35%) for SR and US$285/ha (-20%) for FP. Little change in grain yield resulted from applying P at rates beyond 60 kg P_2O_5/ha, but the introduction of K in combination with N and P returned a yield level that was statistically equivalent to, yet less profitable than, the best complete treatment.

Table 2. Effect of fertilizer treatments on pearl millet grain and stover yield and net profits, Haryana.

Treatments	Grain yield	Stover yield	Net profit[2]
	- - - - - t/ha- - - - -		US$/ha
1. N_{150} P_{90} K_{80} plus S+Micros'[1]	3.18	7.61	154
2. N_{150} P_{60} K_{80} plus S+Micros'	3.28	7.70	156
3. N_{150} P_{30} K_{80} plus S+Micros'	2.95	6.85	159
4. N_{150} P_{0} K_{80} plus S+Micros'	2.89	5.95	145
5. N_{150} P_{60} K_{40} plus S+Micros'	2.99	6.75	146
6. N_{150} P_{60} K_{20} plus S+Micros'	3.21	7.11	156
7. N_{150} P_{60} K_{0} plus S+Micros'	2.91	5.74	136
8. N_{150} P_{60} K_{80}	3.06	6.30	161
9. N_{125} P_{62} (State recommendation)	2.50	4.45	77
10. N_{150} P_{60} (Farmers' practice)	2.75	4.90	90
CD = 5%	0.23	0.38	

[1] Includes 30 kg S/ha, 5 kg Zn/ha, 3.8 kg Fe/ha, and 3 kg Mn/ha. Urea, diammonium phosphate, and potassium chloride were the N, P, and K sources, while Zn, Fe, Mn, and Cu were supplied via respective sulfate sources.

[2] 1 US$ = 45.28 Indian Rupees.

Large improvements in stover biomass were achieved. The largest increases were seen at the highest levels of nutrient input, which included K plus the S+micronutrient package.

Similar to the grain yield response, when K fertilizer was applied, a significant increase was measured relative to the FP and SR treatments. The same was not true if K was omitted and only the S+micronutrient package was applied.

Leaf biomass from pigeonpea is commonly used as fodder, while plant stems are often used for either fuel or mulching. After the rainy season, mulched stems become soft and decomposable…they in turn can be returned to the field to help improve organic matter, soil physical properties, and nutrient availability. Total biomass production from pigeonpea is estimated at 13 million metric tons (M t) using normal farmer practices. With adoption of SSNM in only 25% of Haryana's planted area, it could increase to 15 M t.

Pearl Millet Response

Highest grain yields were achieved with treatments supplying at least 60 kg P_2O_5/ha and 80 kg K_2O/ha. However, lower rates of K seemed able to produce statistically equivalent grain yields if co-applied with a S+micronutrient package (**Table 2**). Although both the SR and FP yields were inferior to the improved treatments, FP yielded more than the SR, which highlights the inadequate N recommendations being promoted by the state. Net return from grain was highest (US$161/ha) with the NPK combination, which was 109% and 79% higher than the SR and FP, respectively.

Pearl millet is an important foodgrain crop.

As in pigeonpea, enhanced nutrient availability produced large improvements in stover biomass. Although K alone had a large effect on pearl millet stover production (42% more than the SR and 28% more than FP), much higher biomass production was possible while still maintaining high grain yield and profitability, under the complete treatments—the best at this site being 150-60-80 kg N-P_2O_5-K_2O/ha plus the S+micronutrient package.

Pearl millet stover is also used as animal fodder, but the potential is great for recycling this biomass back into the field for the purposes of improving soil qualities such as organic carbon content, soil physical properties, and particularly K, secondary nutrients, and micronutrients. At current levels of productivity, total pearl millet stover production is estimated 15 M t. However, with adoption of SSNM practice on 25% of Haryana's planted area, an additional 3 M t could become available.

These results provide a clear example of the value of SSNM research in narrowing the gap between actual farmers' yield and true yield potential. BC

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Alfalfa Production as a Function of Soil Extractable Phosphorus in the Semi-arid Pampas

By Martín Díaz-Zorita and Daniel E. Buschiazzo

This research provides insight into soil nutrient limitations for the main alfalfa producing soils of the semi-arid Pampas. Comparisons of critical extractable soil phosphorus (P) values were made among four common soil testing procedures.

The semi-arid Pampas region of Argentina is commonly characterized as having nitrogen (N), P, and sulfur (S) deficiency as a result of low native soil fertility and wind erosion. In reality, information on annual and pasture crop responses to nutrients is scarce, variable, and sometimes contradictory. Variability in crop response to P fertilization might be explained by differences in total and/or available soil P. Results from a climosequence analysis describe similar total P levels among agricultural soils in the region (Prüeß et al., 1992). Thus, variations in crop response must at least be partially explained by differences in available soil P.

Several factors can modify soil P availability. These include: phosphate sorption by amorphous iron (Fe) and aluminum (Al) oxides, as well as precipitation of calcium phosphate in the presence of excess carbonate. Variability in crop response to P could also be attributed to other nutrient deficiencies. For example, in the eastern part of La Pampa Province, S deficiency is known to reduce alfalfa dry matter responses to P and N fertilization (Bariggi et al., 1975; Díaz-Zorita and Fernández-Canigia, 1998). Zinc (Zn) and copper (Cu) are also known yield-limiting factors for this region of Argentina (González and Buschiazzo, 1996).

The Bray Kurtz 1 procedure is commonly used for the evaluation of available P for annual and pasture crops, but is less effective for soils with free calcium carbonate contents. The Olsen extraction procedure is thought to be more reliable for high pH soils, while the Mehlich 3 procedure is widely promoted for its multi-nutrient extraction capability and reduced soil analysis costs. The objective of this study was to determine the relationship between four different P extraction procedures and alfalfa dry matter production under greenhouse conditions.

Surface horizons from 10 Entic Haplustoll soils were selected to obtain a range of available P levels. Main soil properties are presented in **Table 1**. Available soil P was determined using the Bray Kurtz 1 (Beech and Leach, 1989), Olsen (Olsen and Sommers, 1982), Kelowna (Buschiazzo et al., 1999), and Mehlich 3 (Mehlich, 1984) procedures (**Table 2**). Four fertilization treatments (**Table 3**) were added to 1,400 cm^3 pots arranged in a randomized complete block (RCB)

Table 1. Mean physicochemical properties of the test soils from the semi-arid Pampas, Argentina.

Soil	Clay	Silt	Sand	SOM	Nt	Water pH	Alo	Feo
	- - - - - - - - - - - -	- - - - - - -	% - - - - -	- - - - - - - -			- - - mg/kg	- - -
A	5.8	7.0	87.2	1.5	0.08	6.6	1,105	565
B	11.5	18.0	70.5	1.1	0.06	8.1	1,360	557
C	11.8	29.2	59.0	2.8	0.14	6.5	930	1,032
D	10.7	35.6	53.7	2.2	0.10	8.0	1,540	560
E	9.3	43.5	47.2	5.2	0.27	7.2	1,535	597
F	18.5	34.4	47.1	2.7	0.12	6.2	1,255	1,187
G	30.5	45.8	24.3	5.2	0.27	5.7	1,705	1,372
H	10.0	9.3	80.7	1.2	0.06	5.8	1,155	607
I	10.0	13.3	76.7	2.5	0.11	5.8	1,135	675
J	12.2	19.1	68.7	2.1	0.10	5.9	730	900

SOM = soil organic matter, Nt = total nitrogen, Alo = aluminum amorphous oxides; Feo = iron amorphous oxides

design with three replicates. Pots were planted to rhizobium-inoculated alfalfa. Aerial dry matter (DM) was measured at 108 and 166 days after seeding. Total P, S, potassium (K), Ca, magnesium (Mg), Fe, Cu, and Zn were determined in composite samples from each treatment, sampling date, and test soil. Results of DM production were analyzed by analysis of variance (ANOVA) procedures and the Tukey mean comparison test. The mean crop response in each soil was related to soil test P as determined by each of the four extraction procedures using a linear-segmented model.

Table 2. Soil extractable P levels for four different procedures on 10 soils from the semi-arid Pampas, Argentina.

Soil	Bray Kurtz 1	Olsen	Kelowna	Mehlich 3
	- - - - - - - - - - - -	mg/kg	- - - - - - - - - - - -	
A	9.5	–	–	16.9
B	3.6	–	11.5	–
C	24.2	8.6	26.9	26.5
D	9.3	2.6	10.8	13.5
E	10.6	3.7	14.2	15.9
F	37.3	18.6	37.6	35.2
G	67.2	61.5	86.1	56.8
H	9.2	3.1	10.2	14.7
I	29.0	11.6	40.2	28.0
J	5.9	6.2	13.7	11.3

Results

Alfalfa dry matter production varied between 1.17 and 7.05 g/pot per sampling date, showing significant interactions between soil-type and fertilization treatment. The effect of sampling date was independent of soil-type and fertilization treatment. Thus, treatment effects were analyzed separately for each soil using the average of the two sampling dates.

Treatments produced significant differences (p=0.05) in dry matter production in soils A, B, C, E, H, and J compared to the control (**Table 4**). Soils A and H had a significant dry matter response to P fertilization alone. The complete minus P treatment (CF - P) increased dry matter production relative to the control in soils A, C, E, and H. Only soils A and B produced less dry matter than the complete treatment (CF) under the CF - P treatment. Together, these results suggest that most soils showed relevant changes in dry matter production after fertilization with nutrients other than P.

The absence of a response to P and other nutrients in the soils D, F, G, and I is explained by high extractable P and soil organic matter contents, and low sand contents (**Table 1**). Thus, under the experimental conditions, these soils were able to provide higher nutrient supplies through mineralization. Differences in DM production were partially explained by differences in tissue P levels [DM (g/pot) = 0.95 + 4.45 P_{tv} + 3.22 P_{tv}^2, $r^2 = 0.575$, $p=0.05$].

Tissue analysis of the non-fertilized control treatments showed

Table 3. Fertilization treatments and levels of applied nutrients.

Treatment	P_2O_5	K_2O	S	N	B	Cu
	- - - - - - - -	- - - - - - -	kg/ha-	- - - - - - -	- - - - - - - -	
Control	–	–	–	–	–	–
Complete fertilization (CF)	79	52.4	26.2	22.5	0.6	1.5
Complete without P (CF - P)	–	52.4	26.2	24.0	0.6	1.5
P fertilization (PF)	79	52.4	–	–	–	–

Table 4. Effects of four fertilizer treatments on alfalfa dry matter production (average of two sampling dates) using 10 semi-arid Pampas soils.

	Treatment			
Soil	Control	PF	CF - P	CF
	- - - - - - - - - - - -	g/pot	- - - - - - - - - - - -	
A	1.54 c	2.57 b	2.40 b	3.56 a
B	2.04 b	2.36 b	2.32 b	4.09 a
C	3.06 b	3.31 b	4.30 a	4.49 a
D	2.22	2.94	2.69	3.82
E	3.99 c	4.82 ab	4.43 bc	5.71 a
F	3.53	3.89	4.47	4.16
G	4.78	4.90	4.71	4.76
H	2.74 b	3.96 a	3.50 a	4.50 a
I	3.22	3.23	4.01	4.68
J	2.53 c	3.25 bc	3.33 ab	4.23 a

Different letters indicate significant differences between treatments (p=0.05).

S contents below the critical level of 0.22% in most soils, which suggests that S, and not P, could be the limiting nutrient for optimal alfalfa production. Several authors have obtained similar results after fertilizing alfalfa and pastures in field studies in the area (Díaz-Zorita and Fernández-Canigia, 1998). In soils A, B, E, F, and H, the tissue Zn contents in control pots were higher than those in treatments fertilized with P alone, suggesting that P fertilization under low Zn availability could induce Zn deficiency and lower crop yield. Tissue Mg contents were also below the critical level for optimum alfalfa dry matter production, which may be due to cation competition between K and Mg in soils with high native K levels.

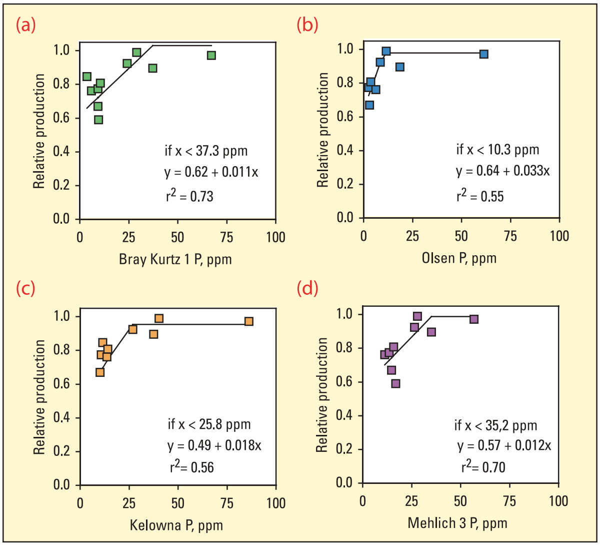
Phosphorus concentration in alfalfa tissues were significantly correlated with extractable soil P levels no matter which extraction procedure was used.

Relative DM production was related to extractable soil P contents when expressed either as the ratio between the control and PF treatment, or the ratio between the CF - P and CF treatments (**Figure 1**).

Despite large variation in the measured values, strong linear relationships existed between the four extracting procedures (**Table 5**). Since no differences existed between the duration, intensity, or soil:extractant solution ratio used in the extraction procedures, the lower extractable soil P values obtained with the Olsen procedure is explained by the lower reactivity of the extraction solution, $NaHCO_3$, compared to the extraction solutions used in the Bray Kurtz 1 or Mehlich 3 procedures.

The critical extractable soil P content, based on the Bray Kurtz 1 procedure, was greater than those values suggested in field studies (Peaslee, 1978; Culot, 1986). This is likely an artifact common to pot studies wherein small soil volumes allow full exploration by plant roots and complete exhaustion of available soil nutrients. As a result, the critical levels for alfalfa dry matter response to P fertilization should not be considered conclusive.

Figure 1. Relationship between relative alfalfa dry matter production, as the ratio CF -P/CF, and soil P levels extracted according to (a) Bray Kurtz 1, (b) Olsen, (c) Kelowna, and (d) Mehlich 3 procedures.



Conclusions

Alfalfa dry matter production in soils of the semi-arid Pampas region, under greenhouse growing conditions, depends on extractable soil P and the availability of other nutrients such as S, Mg, and Zn. The response of alfalfa to P fertilization could be partially explained by the extractable soil P contents determined by the Bray Kurtz 1, Olsen, Kelowna, or Mehlich 3 procedures. The critical

Table 5. Linear relationship between soil extractable P levels extracted by four different procedures.

$P_{Olsen} = -7.2 + 0.90\ P_{Bray\ Kurtz\ 1}$	$P_{Bray\ Kurtz\ 1} = 9.7 + 0.99\ P_{Olsen}$	$r^2 = 0.89$
$P_{Kelowna} = 2.2 + 1.18\ P_{Bray\ Kurtz\ 1}$	$P_{Bray\ Kurtz\ 1} = -0.9 + 0.81\ P_{Kelowna}$	$r^2 = 0.96$
$P_{Mehlich\ III} = 8.0 + 0.73\ P_{Bray\ Kurtz\ 1}$	$P_{Bray\ Kurtz\ 1} = -10.5 + 1.35\ P_{Mehlich\ III}$	$r^2 = 0.98$
$P_{Kelowna} = 11.8 + 1.25\ P_{Olsen}$	$P_{Olsen} = -7.8 + 0.74\ P_{Kelowna}$	$r^2 = 0.93$
$P_{Mehlich\ III} = 9.6 + 1.44\ P_{Olsen}$	$P_{Olsen} = -4.3 + 0.58\ P_{Mehlich\ III}$	$r^2 = 0.84$
$P_{Mehlich\ III} = 6.27 + 0.66\ P_{Kelowna}$	$P_{Kelowna} = -5.4 + 1.32\ P_{Mehlich\ III}$	$r^2 = 0.87$

extractable soil P content for maximum alfalfa dry matter production depended upon the extraction procedure. Further field study is required to estimate critical P levels for fertilization recommendations in this region. In such studies, it is suggested to apply adequate levels of S, Mg, and Zn, since these nutrients were observed to be limiting factors for optimal alfalfa growth.

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Sugarcane Production and Changes in Soil Phosphorus Forms after Organic and Inorganic Fertilization

By Carlos Henríquez, Floria Bertsch, and Randy Killorn

Where adequate organic sources exist, high yield sugarcane production systems should integrate their use with inorganic fertilizers. Both have a role in providing nutrients to crops and improving the physical microbiological properties of soil. An integrated strategy promotes agro-ecosystem diversity and maximum economic yield (MEY) agriculture.

Adopting appropriate soil and crop management practices positively affects chemical, physical, and biological conditions of soil. Addition of phosphorus (P) may impact soil P forms and thus the timing and intensity of P availability. Both organic and inorganic sources enhance soil P availability and crop yields. In tropical soils, the effectiveness of either is often site-specific (Ball-Coelho et al., 1993; Reddy et al., 1999; Sui et al., 1999). Overall, research results suggest the need for more investigation regarding the impact of fertilization on P cycling in tropical agro-ecosystems.

Sugarcane production in Costa Rica is mainly located on high organic matter soils derived from volcanic ash (Andisols). Andisols are strongly P-fixing due to adsorption at the active surfaces of allophane and imogolite minerals and also by aluminum (Al)-humus complexes through ligand-exchange reactions (Sanchez and Uehara, 1980; Molina et al., 1991; Espinosa, 1992). High organic matter contents imply that the organic P fraction plays an important role in satisfying the crop's demand. Conditions typical of the soil and region combine to complicate the estimation of soil P status and challenge the ability of soil testing to adequately predict soil P availability (Beck and Sanchez, 1994; Espinosa, 1992).

Sugarcane production without added fertilizer can seriously deplete all forms of soil P on soils derived from volcanic ash.

This experiment studied soil P forms resulting from application of organic and inorganic fertilizers on an Andisol. Yield response data for the nutrient sources applied to sugar cane was also evaluated. A sugarcane (*Sacharum* sp. var H-611721) field experiment conducted from 1997 to 2002 on a Typic Hapludand at Juan Viñas, Costa Rica (1,000 meters above sea level and 2,000 mm of rain per year) was harvested twice during this period. Yield of cane and sugar were measured along with total P uptake. Treatments consisted of 0, 50, and 100% of the inorganic fertilizer recommendation in combination with compost at either 0 or 8 t/ha (**Table 1**).

Table 1. Estimated amounts of nutrients (N, P, and K) applied as fertilizer on sugarcane over 4 years on a Typic Hapludand at Juan Viñas, Costa Rica.

Treatments		Nitrogen			Phosphorus			Potassium		
Compost	Fertilization	Organic	Mineral	Total	Organic	Mineral	Total	Organic	Mineral	Total
		kg/ha								
0	0	0	0	0	0	0	0	0	0	0
0	50%	0	245	245	0	59	59	0	162	162
0	100%	0	490	490	0	118	118	0	323	323
8 t/ha	50%	46	245	291	10	59	69	26	162	188
8 t/ha	100%	46	490	536	10	118	128	26	323	359

Nutrients were applied at the beginning of each growing cycle.

Soil samples were collected, ground (<100 mesh), and analyzed using a modified Hedley P fractionation scheme (Hedley et al., 1982). This technique is a sequential extraction procedure that removes labile inorganic P (Pi) and organic P (Po) followed by the more stable P forms. Inorganic P is first extracted by anion exchange membranes (AEM-P) followed by sodium bicarbonate ($NaHCO_3$), sodium hydroxide (NaOH), and hydrochloric acid (HCl). The sample is then digested in sulfuric acid (H_2SO_4) and hydrogen peroxide (H_2O_2). These inorganic fractions are related to soluble/labile-Pi, labile-Pi, iron (Fe) and Al phosphates, calcium phosphates, and residual P. Extractable organic P was determined by the difference of total P (coming in digested aliquots of $NaHCO_3$ and NaOH) and the Pi initially determined from these extracts. AEM-P and $NaHCO_3$-Pi were summed and expressed as labile-Pi. $NaHCO_3$-Po and NaOH-Po were summed and expressed as extractable-Po. Routine soil analyses were conducted before the beginning of the experiment and at the beginning of the 2001 season (**Table 2**).

Yield Response and P Uptake by Sugarcane

The two yield variables responded differently to nutrient application (**Table 3**). Fresh cane yield was consistently higher for all treatments supplying nutrients compared to the control. Yields ranged from 106 to 145 t/ha in the first harvest (1999) and from 163 to 258 t/ha in the ratoon season (2001). Accumulated yield was nearly 50% higher than the control when inorganic and organic sources were co-applied at their higher levels. Despite these yield responses, variability prevented any statistical differences among treatments supplying nutrients. Nutrient application over this time frame did not seem to affect the amount of sugar produced per tonne of fresh cane.

Table 2. Selected properties of the soil used in the study, Juan Viñas, Costa Rica.

Treatments			P	Ca	Mg	K	Acidity	O.M.
Compost	Fertilizer	pH H_2O	mg/kg	cmol$_{(+)}$/kg				g/kg
1997 †		5.0	3.0	2.19	0.19	0.11	1.1	-
2001 ‡								
0	0	5.2	4.6	4.65	0.30	0.09	0.17	160
0	50%	4.9	4.8	5.85	0.33	0.10	0.20	140
0	100%	4.8	5.5	3.49	0.23	0.10	0.27	151
8 t/ha	50%	4.8	5.5	4.49	0.28	0.09	0.17	158
8 t/ha	100%	4.9	5.8	3.91	0.11	0.11	0.22	172
Critical level		5.5	10.0	4.00	1.00	0.20	<0.5	-

† Initial soil sampling before beginning the experiment
‡ 1.5 t/ha of dolomite was applied in 1998

Table 3. Sugarcane yields obtained after two growth cycles during 4 years on a Typic Hapludand, Juan Viñas, Costa Rica.

Treatments		1999 yield		2001 yield		Accumulated
Compost	Fertilizer	kg sugar/t	t/ha	kg sugar/t	t/ha	yield, t/ha
0	0	112	106 b	101	163 b	269 b
0	50%	111	134 a	98	218 a	352 a
0	100%	113	142 a	103	239 a	381 a
8 t/ha	50%	115	139 a	108	224 a	363 a
8 t/ha	100%	119	145 a	96	258 a	403 a
Significance		ns	**	ns	*	**

ns Not significant at p=0.05

* Significance at p=0.01 to 0.05

** Significance at p=0.01

Means within the same column followed by the same letter are not significantly different (p=0.05) by LSD test.

Phosphorus uptake by sugar cane is shown (**Figure 1**). Total uptake by sugar cane yielding 180 t/ha in 700 days (2-year growth cycle) was approximately 60 kg/ha.

Soil P Forms

According to the fractionation scheme applied, the proportions of soil P forms in the fertilizer plus compost treatments averaged: 0.4% labile-P, 6.4% NaOH extractable-Pi, 9.2% HCl extractable-Pi, 32.5% extractable-Po, and 51.4% residual-P. Soil P forms that were most correlated with yield and applied P were labile-P and NaOH-Pi (**Figure 2**). The NaOH-Pi fraction represents P held by chemisorption to Fe and Al components of soil surfaces. This fraction is thought to act as a sink for inorganic fertilizer applied and labile-Pi. Little relation was found between cane yield and organic-, residual-, or total-P.

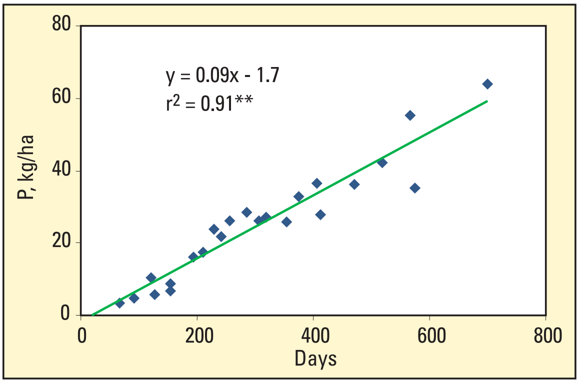

Figure 1. Total P uptake of sugarcane on a Typic Hapu-land, Juan Viñas, Costa Rica.

Summary

Applied P was mainly correlated with labile-Pi and NaOH-Pi, but results suggest active participation from nearly all soil P fractions in maintaining labile-Pi levels in this soil. Adsorption-desorption processes act intensively in this soil and it was possible to see the effect of fertilizer in desorbing P for a long time after its application. Crop production without added fertilizer will seriously deplete all forms of soil P. **BC**

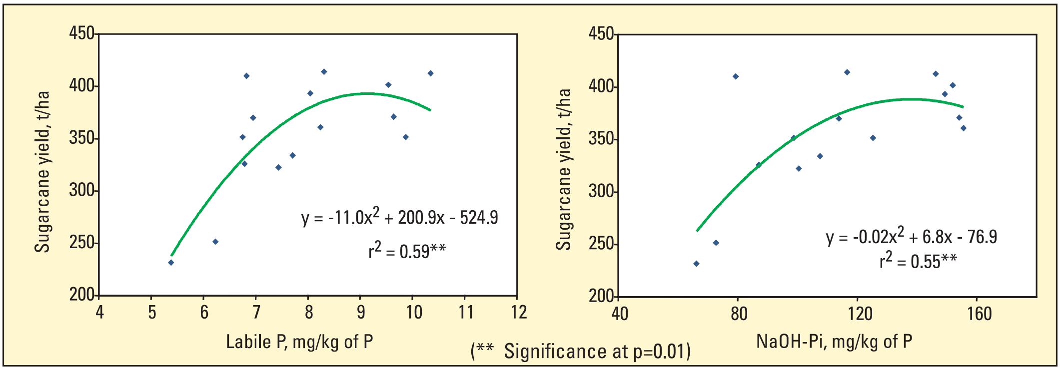

Figure 2. Relation between accumulated sugarcane yields and labile-Pi and NaOH-Pi on an Andisol. Juan Viñas, Costa Rica.

More study is needed regarding impact of P fertilization on P cycling in tropical agro-ecosystems.

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Acknowledgments

The authors acknowledge Dr. José Espinosa and the PPI/PPIC Northern Latin America Program (INPOFOS), as well as the valuable cooperation of the staff and workers from Hacienda Juan Viñas and the Laboratory of Soil and Plant Analysis in Centro de Investigaciones Agronomicas at the Universidad de Costa Rica. Special thanks to Gloria Melendez, Luis Garcia, Pablo Lopez, and Ivania Cartin.

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LIMITATIONS OF THE MIND

I count as great fortune the opportunity my work has provided in meeting people who tenaciously harness intellect with logic and compassion, and who view the inhabitants of this world with understanding and tolerance. *Limitations of the mind* is a phrase I borrow from a friend in Pakistan, Dr. Zafar Altaf. In one of his books, he cites Banham's 'The Anatomy of Change'. He offers what I consider to be a key principle and ingredient for progress: "What cannot be readily bought are the teams of skilled, committed and experienced people." Together, teams of people can challenge *limitations of the mind.*

Over the past decade and more, the truth of Banham's statement repeatedly proves itself in what I see and hear as I visit with PPI/PPIC staff and their cooperators and colleagues. Regarding the Institute, its construct as originally devised and as it evolves in each and every one of its programs, is centered on building teams ... of researchers, extension agronomists, farmers, decision makers and industry ... all focused on improving soil productivity to overcome limitations of the soil ... and the minds of those who tend them. These teams of skilled, committed and experienced people from different disciplines and diverse backgrounds are fundamentally important to the tasks of increasing prosperity for farmers, food sufficiency for nations, and environmental security for our global village. They are also fundamentally critical in meeting the challenges still before us, to the challenges that limit our minds.

I offer my sincere thanks to all who labor with us. It's a great experience and it provides great satisfaction as we view the tremendous progress made. But, we haven't crossed the finish line. There is still much left to do.

Agronomists and soil scientists are literally, people of the earth ... people with their feet on the ground and their hands in the soil. They are my kind of people because where we work and what we do is uniquely basic to social development and progress. **What's slowing our progress; what's holding us back? Is it *limitations of the mind*?**

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

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