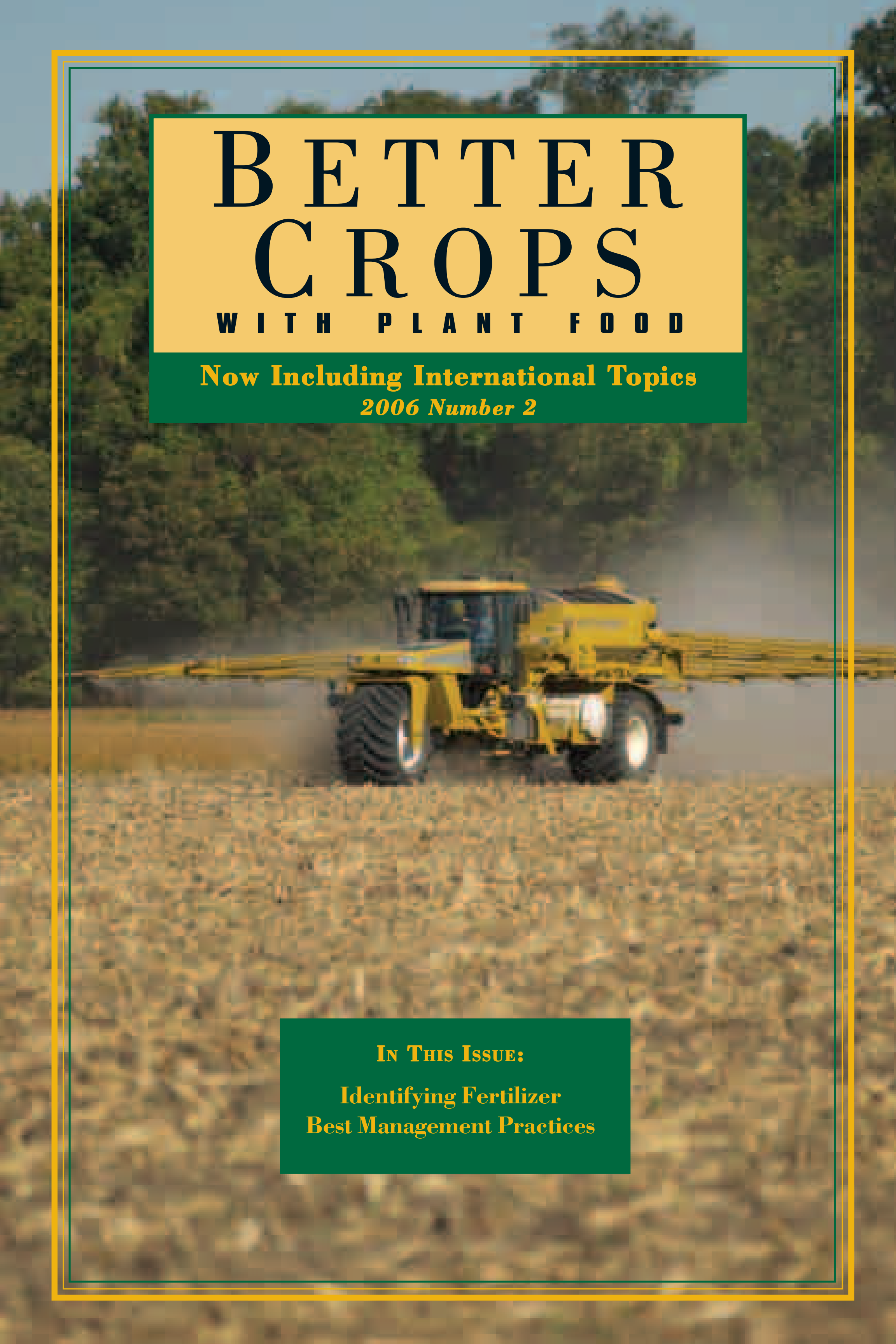


BETTER CROPS

WITH PLANT FOOD

Now Including International Topics
2006 Number 2

In This Issue:

Identifying Fertilizer Best Management Practices

BETTER CROPS
WITH PLANT FOOD

Vol. XC (90) 2006, No. 2

Our cover: Fertilizer application.
Photo credit: Courtesy of AGCO.

Editor: Donald L. Armstrong
Assistant Editor: Katherine P. Griffin
Circulation Manager: Carol Mees
Design: Kathy Hefner

Potash & Phosphate Institute (PPI)
W.J. Doyle, Chairman of the Board
PotashCorp
F.W. Corrigan, Vice Chairman of the Board
Mosaic
W.J. Whitacre, Chairman, Finance Committee
Simplot

HEADQUARTERS: NORCROSS, GEORGIA, U.S.A.
T.L. Roberts, President
C.V. Holcomb, Assistant Treasurer
S.J. Couch, Director, IT and Member Programs/Conferences
B. Rose, Statistics/Accounting

AMERICAS PROGRAM-Brookings, South Dakota
P.E. Fixen, Senior Vice President,
Americas Program Coordinator, and Director of Research
P. Pates, Secretary

REGIONAL DIRECTORS-North America
T.W. Bruulsema, Guelph, Ontario
A.M. Johnston, Saskatoon, Saskatchewan
R.L. Mikkelsen, Davis, California
T.S. Murrell, Woodbury, Minnesota
C.S. Snyder, Conway, Arkansas
W.M. Stewart, San Antonio, Texas

INTERNATIONAL PROGRAMS
Potash & Phosphate Institute of Canada (PPIC)
A.M. Johnston, President, PPIC, Asia Program Coordinator,
Saskatoon, Saskatchewan
P.E. Fixen, Americas Program Coordinator,
Brookings, South Dakota
L.M. Doell, Corporate Secretary, PPIC, and
Administrative Assistant, Saskatoon, Saskatchewan
G. Sulewski, Agronomist, Saskatoon, Saskatchewan

INTERNATIONAL PROGRAM LOCATIONS
Brazil T. Yamada, POTAFOS, Piracicaba
China Ji-yun Jin, Beijing
Ping He, Beijing
Shutian Li, Beijing
Fang Chen, Wuhan
Shihua Tu, Chengdu
India K.N. Tiwari, Gurgaon, Haryana
T.N. Rao, Hyderabad, Andhra Pradesh
K. Majumdar, Calcutta (Kolkata), West Bengal
Northern Latin America J. Espinosa, Quito, Ecuador
Latin America-Southern Cone F.O. Garcia, Buenos Aires, Argentina
Southeast Asia C. Witt, Singapore

Foundation for Agronomic Research (FAR), Monticello, Illinois
H.F. Reetz, Jr., President

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.
Copyright 2006 by Potash & Phosphate Institute.

The Government of Saskatchewan helps make the International Section of this publication possible through its resource tax funding. We thank them for their support of this important educational project.

CONTENTS

Members: Agrium Inc. • Intrepid Mining, LLC • Mosaic • PotashCorp • Simplot

Fertilizer Best Management Practices—Making the Best Better

By Paul E. Fixen and Harold F. Reetz

Fertilizer best management practices (BMPs) are being identified and refined by PPI staff with support obtained by the Foundation for Agronomic Research (FAR), through a Conservation Innovation Grant (CIG) awarded by the USDA-Natural Resources Conservation Service (NRCS). The project under the 3-year grant (68-3A75-5-166) runs through 2008.

Stakeholder teams are being organized in each of six regions in North America. PPI regional directors will chair these groups, composed of a cross-section of members representing Cooperative Extension staff, farmers, NRCS personnel, local agribusinesses, crop consultants, and others as appropriate. The teams will meet at least twice a year during the project to review materials being developed and to advise the project leaders.

The BMP guidelines and other training materials will be presented to producers and stakeholders through field days and at national and regional Information Agriculture conferences. A National Fertilizer Best Management Practices conference is planned as part of InfoAg 2007 to promote understanding and adoption of new BMPs. Information will also be shared through websites, on-line modules, and other training methods.

BMPs for Fertilizer Management in the Great Plains

Practice	Best Practice	Making Progress	Improvements Required
Diagnostic			
Soil testing	Annually test for N where it is applied. Less than every 3 years for P and K.	Less than one-fourth to one-third of fields tested each year.	Never test, or last soil test more than 10 years old.
Plant tissue analysis	Routinely use tissue sampling to evaluate effectiveness of fertility program.	Occasionally use tissue sampling for diagnostic purposes.	No tissue samples collected.
Yield goals set	Develop crop- and field-specific yield goals based on measured yield history and crop sequence.	Develop yield goals for each crop on the farm, regardless of field.	No yield goals considered in planning, or arbitrary or unrealistic yield goals are used.
Nutrient budgets	Consider last year's crop removal and this year's yield goal, in matching fertilizer applied with current soil test results.	Consider crop nutrient removal based on a desired yield goal, or replace last year's removal regardless of soil test level.	No consideration for crop nutrient removal or past production.
Fertilizer Application			
Right rates and balance	Meet the specific needs of all nutrients.	Fertilizers applied as a fixed blend based on N needs.	Crop N rate set with no consideration to other nutrient needs or variation among fields.
Right form	Consider N form when selecting fertilizer types and application timing.	Incorporate broadcast urea or UAN within 24 hours, unless on soils with low pH or low soil temperatures.	Unaware of any form effects. Surface broadcast urea or UAN with no incorporation in warm weather.
Right placement	Use band placement of some nutrients, and place at least some of the less mobile nutrients near seed.	Broadcast and incorporate all fertilizer throughout surface soil.	Broadcast application.
Right timing	Consider timing of crop uptake and plant source availability when considering time of application. Where possible, use fertigation to "spoon-feed" the crop N throughout the season.	Apply all N before seeding.	All nutrients applied well in advance of seeding.
Site-specific management	Evaluating field variation when making fertilizer application decisions and apply N variably based on in-field zones.	Fields are grouped based on the dominant soil-landscape formation.	No consideration to field variability in fertilizer application.
Minimizing Nutrient Losses			
Leaching avoidance on sensitive soils and landscapes	Full use of N BMPs: soil NO_3 testing, split N application, fall cover crops, groundwater monitoring.	Use of half the BMPs at left.	No consideration of potential leaching losses or use of BMPs.
Conservation tillage	Adoption of no-till or strip-till system.	Minimum tillage used to maintain reasonable (30%) residue cover.	Conventional tillage with the majority of the residue buried.
Buffer strips	Have buffer strips next to surface waters and reduce tillage near the area to minimize soil transport.	No buffer maintained, but use no-till adjacent to surface water edge.	Surface water not considered in management of fertilizers.
Irrigation management	Use center pivot, LEPA, or subsurface drip systems and base water application on local crop water use and PET monitoring stations, thus avoiding water and nutrient waste.	If using flood irrigation fields are diked so that excess water does not escape the field.	Water is applied with little regard to soil moisture or PET. Excess water containing sediments and nutrients is allowed to leave the field and run into nearby streams.

Tables such as this are available for review on-line for each of the six cropping systems.

The six cropping systems that have been identified for this project are:

- Irrigated corn in the Great Plains
- Potato production in the Northwest
- Spring cereal/pulse rotations in North Dakota
- Midwest corn/soybean systems
- Cotton rotations in the Midsouth
- Forage crops for dairy farms in the Northeast

The concept of applying the right fertilizer at the "right rate, right time, and right place" is a guiding theme in the series. This issue of *Better Crops with Plant Food* features six brief articles discussing these topics. They serve as a starting point for the efforts of the regional CIG teams. Some BMPs are common to all cropping systems, while others are not. To avoid repeating these BMPs, they are included in the article beginning on page 4...but the focus of the remaining articles is on the unique practices for the specific cropping systems. Even more thorough discussion of the six cropping systems appears in a series of *News & Views* which are available in print or as PDF files at the PPI website: >**www.ppi-ppic.org**<. BC

Dr. Fixen is PPI Senior Vice President, Americas Program Coordinator, and Director of Research, located at Brookings, South Dakota; e-mail: pfixen@ppi-far.org. Dr. Reetz is FAR President, located at Monticello, Illinois; e-mail: hreetz@ppi-far.org.

Conserving Resources and Building Productivity...A Case for Fertilizer BMPs

By Mike Stewart

Best management practices (BMPs) are a hot topic these days. Farmers in the Great Plains have implemented soil conservation practices that rival any other resource conservation activity in the world. The resulting reduction in soil erosion by wind and water...along with moisture conservation practices... have improved soils while increasing crop yields and improving whole-farm economics.

Fertilizer nutrients are essential in meeting the crop yield and quality goals of modern agriculture. With reduced tillage systems, many semiarid regions have been able to intensify cropping, thus reducing the use of fallow for soil moisture accumulation, and increasing the need to replace the nutrients removed by the increased cropping intensity. How we handle fertilizer inputs (e.g., rate, timing, and placement) provides the foundation for fertilizer BMPs and the potential for maximum positive economic returns from fertilizer use.

Matching Nutrient Supply with Crop Requirements

This involves using all available information to establish the soil nutrient status and crop requirements prior to making fertilizer application decisions. Specific BMPs include soil testing, plant analyses, setting realistic yield goals, and balancing nutrient inputs with crop removal at optimum soil test levels.

Soil Testing The main science-based tool we have to estimate a soil's capacity to supply nutrients on agricultural land is soil testing. The soil testing process is based on soil samples being taken from representative areas in a field, analyzed using an appropriate chemical extraction method, and either correlated with plant nutrient uptake or calibrated with crop yield response. Resulting fertilizer recommendations are based on how a particular crop responded to a nutrient, using the average response from a multi-year and multi-site data set. If nutrient levels in a soil are allowed to decline to the point of limiting yield potential, substantial economic losses can be expected. This was shown clearly with phosphorus (P) in a long-term corn-soybean study in Kansas (Gordon, 2003).

The Dust Bowl of the 1930s in the U.S. was a lesson to the world concerning the importance of conserving natural resources. That is one of the goals of BMPs.

Figure 1 shows that annual application of 30 lb P_2O_5/A over 42 years maintained soil test P at near the initial (1960) level until about 1985. Since then, soil P levels have declined. Corn grain yields were 11% greater for the period 1985-2002 than for 1960-1984. This indicates that the 30 lb P_2O_5/A rate was not keeping pace with the crop removal rate. Where no P fertilizer was applied, soil test P declined to half of the original value.

Plant Analysis The term plant analysis refers to the total or quantitative analysis of nutrients in plant tissue. Plant analysis

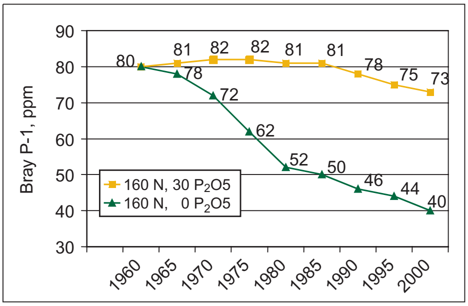


Figure 1. Neglecting soil fertility severely depleted reserves of soil P in a long-term corn-soybean rotation study (Kansas, Gordon, 2003).

works with soil testing to evaluate soil fertility and overall nutrient availability. Plant analysis is used in-season to help evaluate nutrient deficiencies and take corrective action on the current crop or future crops.

Establishing Realistic Yield Goals Suggested recommended application rates are often tied to yield goals for several nutrients. Yield records should be used to set individual realistic, but progressive, yield goals for each field. Appropriate yield goals for a specific field should be high enough to take advantage of high production years when they occur, but not so high as to jeopardize environmental stewardship and/or profitability when environmental conditions are not as favorable. Appropriate yield goals fall between the average yield obtained in a field over the past 3 to 5 years and the highest yield ever obtained in a particular field (Leikam et al., 2003).

Nutrient Budgets There are a number of situations where crop advisers and farmers find that they can make fairly good estimates of crop nutrient requirements based on what was grown and what was applied in a specific field. Information such as crop yield, grain protein concentration, and straw management can all be used to establish the status of a nutrient such as nitrogen (N). For P and potassium (K), the year-to-year variation in plant-available supply is minor, and annual application based on a balance between soil test levels and crop requirements can avoid depletion or over-application.

Fertilizer Application

Right Rate and Balance of Nutrients Most agronomists have heard about Liebig's Law of the Minimum, which states that the yield of a crop will be determined by the element present in most limiting quantity. In other words, the deficiency of one nutrient cannot be overcome by the excess of another. Use all available tools to ensure that the crop receives complete and balanced nutrition.

Right Fertilizer Form Plants take up the bulk of their nutrients from the soil in specific forms. Fertilizers are formulated to be either in the plant-available forms, or to be easily converted to these forms after application to the soil. In some instances, this conversion limits immediate use by the plant, requiring specific application management for efficient use.

Right Placement An important part of optimizing crop response to a fertilizer nutrient is placing the nutrient in such a way that it provides rapid uptake by the crop and reduces potential losses. The mobility of a nutrient in the soil is a major consideration in its placement. For example, low mobility of P in calcareous soils means that short-term crop utilization of the P is improved considerably when it is placed close to the germinating seed.

Right Timing The demand for a nutrient by a growing crop generally varies through the growing season, with the highest uptake associated with the period of most rapid growth. Timing fertilizer applications so that they provide a plant-available supply of nutrients when the crop needs them is a desirable goal. Plants subject to a deficiency during specific periods of growth may not recover to achieve full yield potential.

Site-Specific Nutrient Management Fertilizing soils rather than fields is an emerging BMP that continues to gain in popularity with technology development. This involves using some form of field diagnostic, such as intensive soil sampling, soil sensing, aerial imagery, or yield mapping...some or all of these measurements can be used to divide fields into management zones or units that can be fertilized independently (Koch et al., 2004). Site-specific fertility management increases the odds that nutrient needs are properly identified and appropriate corrective fertilizer applications are made only where required. This management practice can take into account the natural variation in soil fertility and nutrient supply.

Minimizing Nutrient Loss

From an environmental impact perspective, a major goal of land managers should be to retain soil and associated nutrients within the boundaries of a field and the rooting zone of the crops grown. Fertilizer application based on soil testing and realistic yield goals helps to ensure that proper rates are recommended and applied. This improves plant nutrient use efficiency, and lessens the potential for residual nutrients to accumulate to excessive levels that may pose an environmental threat.

Nutrient Leaching Retention of soluble nutrients in the rooting zone helps ensure efficient recovery and effective use in crop production systems. Leaching occurs when excessive residual nutrients are left in the soil profile and moved below the rooting zone by precipitation or irrigation. While leaching is not a common problem in most semiarid regions, historic use of fallow may result in NO_3-N accumulation below the rooting zone of crops. While there are no reported incidences of P leaching through fertilizer use at soil test recommended rates, leaching of P can occur with the application of livestock manure at rates grossly in excess of crop requirements.

Conservation Tillage, Soil Erosion, and Carbon Sequestration The retention of crop residues on the soil surface significantly reduces the loss of soil by wind and water erosion, while at the same time improves moisture conservation and crop yields.

Crops grown with proper nutrition play a major role in building soil organic matter. A good fertility program results in more biomas and helps sequester atmospheric carbon dioxide (CO_2), thus ultimately resulting in the return of more organic carbon (C) to the soil for storage as soil organic matter.

Field Buffer Strips The movement of N and P into surface waters with eroded soil poses a serious threat to aquatic ecosystems. While some nutrients are required for ecosystem function, too much can lead to a decline in productivity. Eliminating soil erosion from agricultural lands has been a high priority for all farmers. Eroded soil means loss of nutrients, organic matter, and future crop productivity. The adoption of conservation practices such as reduced tillage and buffer strips adjacent to surface water has been shown to reduce undesirable movement of nutrients. BC

Dr. Stewart is PPI Southern and Central Great Plains Region Director, located at San Antonio, Texas; e-mail: mstewart@ppi-far.org.

To view an expanded version of this article and a chart listing fertilizer BMPs for this region, plus additional information and references, visit the PPI website: ***>www.ppi-ppic.org<****.*

References

Gordon, W.B. 2003. Nitrogen and phosphorus management for corn and soybeans grown in rotation. Better Crops. Vol. 87. No. 1. p. 4-5.

Koch, B., R. Khosla, W.M. Frasier, D.G. Westfall, and D. Inman. 2004. Economic feasibility of variable-rate nitrogen application utilizing site-specific management zones. Agron. J. 96: 1572-1580.

Leikam, D.F., R.E. Lamond, and D.B. Mengel. 2003. Soil test interpretations and fertilizer recommendations. MF-2586. Kansas State Univ. Agric. Exp. Stn. and Coop. Ext. Manhattan, KS. (Available online at http://www.oznet.ksu.edu/library/crpsl2/mf2586.pdf) (Verified 30 Dec. 2005.)

Fertilizer BMPs for Cotton in the Midsouth

By Cliff Snyder

Fertilizer best management practices (BMPs) for cotton in the southern U.S. are becoming more widely understood and adopted. However, there are unique differences between cotton production and other major crops that require a closer review.

A common approach to setting realistic yield goals is selecting a value somewhere between an above average yield and a maximum yield you have achieved on that specific field, or one of similar production and management history. Setting a target of 10% above the 3- to 5-year average of crops not suffering a severe yield loss due to drought, excessive rainfall, or pests is also a commonly suggested method. This requires that individual field records be maintained and that only those fields of similar production potential be considered in making estimates. An example for a cotton yield is shown below and considers the best 4 of the previous 5 years, scaled up by 10%. While short of the maximum yield grown, it does provide a means of striving for yield increases. Remember that, over time, yield goals will increase as long as the average yield continues to increase.

Year	Cotton yield, lb of lint/A	
1997	1,320	
1999	890	Average yield = 1,265 lb of lint/A (not using 1999)
2001	1,055	Highest yield = 1,415 lb of lint/A
2003	1,415	Realistic yield goal = 1,265 x 1.10 = 1,392 lb of lint/A
2005	1,270	

Frequently, crop advisers and farmers find that they can make fairly good estimates of crop nutrient requirements based on what was grown previously and what was applied in a specific field. Information such as previous crop yield, soil drainage class, tillage system, and crop residue management can all be used to estimate the status of a nutrient such as N. For most cotton fields, the year-to-year variation in plant-available supply of phosphorus (P) and potassium (K) from the soil is usually relatively minor, and annual fertilizer application based on a balance between soil test levels and crop requirements can avoid depletion or over application.

The way fertilizers are managed can have a major impact on the efficiency of nutrient use by crops and potential impact on the surrounding environment. In all instances, we are striving to improve fertilizer-use efficiency by increasing the pounds of lint per acre for each unit of nutrient applied, without sacrificing yield potential. This is especially true for N, the major nutrient removed from the soil by cotton.

An example of proper nutrient balance is illustrated in a cotton study conducted in Tennessee (**Figure 1**). Improved P nutrition, in both disk-till and no-till systems, raised yields and increased the lint yield per pound of N applied. Being sure to provide adequate P and K nutrition can enhance crop recovery of applied N.

Placing urea-containing N fertilizers beneath the soil surface and crop residues can reduce the volatile losses of ammonia, minimize immobilization in surface residues, increase yields, and enhance fertilizer effectiveness. Responses to source and rate of N may differ between no-till corn and no-till cotton (**Figure 2**) because of the greater amount of crop residue left on the soil surface with corn.

An important part of optimizing crop re-

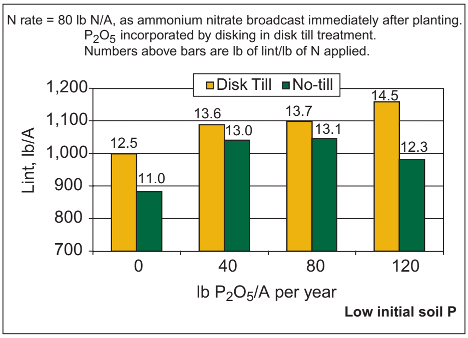


Figure 1. Adequate soil P improves 6-year average cotton yields and response to applied N in Tennessee.
Source: Howard et al., 2001.

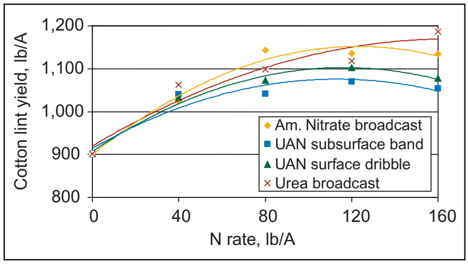


Figure 2. 10-year average response of cotton to N rate and source in Mississippi.
Source: Parvin et al., 2003.

sponse to a fertilizer nutrient is ensuring that the nutrient is placed in such a way that it provides rapid uptake by the crop and reduces potential losses. The mobility of a nutrient in the soil plays a large role in how important placement is. Early research with cotton showed that placement of P becomes less critical as soil test P increases from low to high levels.

Placement can be a powerful management tool to minimize N losses. Where there is an accumulation of surface residues, it is important to place urea-containing N fertilizers beneath the residues. Under ideal conditions, the goal is to apply the N so that it is in the plant-available form and close proximity to roots.

Research in the South has generally shown that when all the N is applied preplant for nonirrigated cotton, yield is optimized (Ebelhar and Welch, 1996; McConnell and Mozaffari, 2004). In irrigated environments, cotton yields and uptake efficiency are often improved with split applications: ¼ to ½ preplant, with the remainder applied before flowering.

Site-Specific Nutrient Management

Fertilizing soils rather than fields is an emerging BMP that continues to gain in popularity with technology development. Using some form of field diagnostic, such as intensive soil sampling, soil sensing, yield mapping, or scouting records, whole fields are divided into management units where the fertilizer application used is independent of the rest of the field.

Aerial imagery and optical plant sensors are being developed which use the crop color and biomass as an indication of N sufficiency. These types of sensing have the potential to provide farmers a practical means of varying the N rate on-the-go. Local calibration of the technology will be needed to make it more useful and economically feasible. In instances where field variability of N is large, this type of application prevents the over-application characteristic of fixed field rates in those areas where the soil N supply is sufficient. While considerable work is underway with corn, there are few cotton studies to draw on (Earnest and Varco, 2005).

Leaching

Leaching occurs when excessive residual nutrients are left in the soil profile and moved below the rooting zone by precipitation. While leaching can be a problem in sandy soils in the humid South, nitrate-N seldom accumulates in silt loam to silty clay loam soil profiles under cotton when the N rate is appropriate for the soil moisture/irrigation regime and the crop yield potential.

While there are no reported incidences of P leaching when fertilizer is used at soil test recommended rates, leached P has been reported with the application of livestock and poultry manure at rates grossly in excess of crop requirements.

Conservation Practices

The retention of crop residues on the soil surface has significantly reduced the water erosion loss of soil, while at the same time improving moisture conservation and cotton yields (Mitchell et al., 2005). When fertilized according to soil test recommended rates, increased cotton yields may lead to higher levels of crop residues returned to the surface of conservation-till fields for erosion protection.

Proper crop nutrition increases crop yields, increases crop biomass, can raise soil organic matter (carbon) content, and can improve the soil supply of organic N. The amount of crop residue returned to the soil is often directly attributed to the positive benefits of fertilization. By allowing crops to capture more carbon dioxide (CO_2) from the atmosphere, more stable soil organic matter can be produced and less atmospheric CO_2…a greenhouse gas…may be released. In long-term rotation studies with cotton in Alabama, yields were found to be highly correlated with soil organic matter content (Mitchell et al., 2005).

The movement of N and P into surface waters with eroded soil poses a serious threat to aquatic ecosystems. Some N and P movement into surface waters may result if relatively water soluble N and P sources are applied when there is a high probability of runoff-producing storm events. Some nutrients are required for the healthy function of aquatic ecosystems, but too much can lead to a decline in aquatic ecosystem productivity. The adoption of conservation practices such as no-till, strip-till, and buffer strips adjacent to surface water have been shown to reduce this unwanted movement of nutrients. In many instances where no-till field management has been adopted, soil erosion and water runoff have been significantly reduced. BC

Dr. Snyder is PPI Southeast Director, located at Conway, Arkansas; e-mail: csnyder@ppi-far.org.

To view a chart listing fertilizer BMPs for this region, plus additional information and references, visit the PPI website: **>www.ppi-ppic.org<**.

References

Earnest, R. and J.J. Varco. 2005. Crop reflectance as an indicator of cotton growth and nitrogen availability. p. 2571-2576. *In* Proc. of the Beltwide Cotton Conference. National Cotton Council, Memphis TN.

Ebelhar, M.W. and R.A. Welch. 1996. Cotton response to multiple split applications of nitrogen. Proc. of the Beltwide Cotton Conference 2:1345-1348. National Cotton Council, Memphis TN.

Howard, D.D., M.E. Essington, J. Logan, R.K. Roberts, and W.M. Percell. 2001. Phosphorus and potassium fertilization of disk-till and no-till cotton. Cotton Science 5:144-155.

McConnell, J.S. and M. Mozaffari. 2004. Yield, petiole nitrate, and node development responses of cotton to early season nitrogen fertilization. J. Plant Nutr. 27(7):1183-1197.

Mitchell, C.C., D. Delaney, and K.S. Balkcom. 2005. Cullars Rotation: The South's oldest continuous soil fertility experiment. Better Crops 89(4):5-9.

Parvin, D., J.J. Varco, and S.W. Martin. 2003. Managing nitrogen for maximum profitability in no-till cotton production. Research Report 2003-005. Department of Agricultural economics. Mississippi State University.

Soil Test Levels in North America, 2005

A new publication from PPI/PPIC summarizes soil test levels for phosphorus (P), potassium (K), and pH…plus magnesium (Mg) and sulfur (S)…in North America. The summary was prepared with the cooperation of about 70 public and private soil testing laboratories. The 45-page publication—titled *Soil Test Levels in North America, 2005*—offers a snapshot view of soil test levels in the U.S. and Canada in 2005.

The 8½ x 11-in. coil-bound booklet is available for purchase at US$25.00 each. The combination package of the printed publication plus the CD-ROM is available for US$30.00. Shipping cost is additional.

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

Best Management Practices for Fertilizer Use on Dairy Farms

By Tom Bruulsema

Dairy farms in the Northeast have made considerable progress in adopting best management practices (BMPs) for managing their impacts on the environment. Nutrient management forms an essential component of such practices, but most BMP publications focus on manure management. This article addresses fertilizer management practices appropriate to the cropping systems that support dairy farms.

Nutrient cycling on dairy farms is intensive. Large amounts of nutrients are both removed from the field in the harvest of forages, and returned in the form of manure. Nutrients also flow onto the farm in the form of purchased feed inputs, and they leave the farm in the form of milk, animals, and other materials sold.

There are three general categories into which we can group the management practices that foster the effective and responsible use of fertilizer nutrients: diagnostics, application, and minimizing nutrient loss from fields.

Diagnostics

Crediting nitrogen (N). Non-legume crops like silage corn or grass forage can demand large amounts of N. Nitrogen is a mobile nutrient. Soils can be sampled for the nitrate form of N, but the sampling must usually be done just before the crop starts taking it up at high rates. The previous crop, and applications of manures and biosolids, can supply large amounts of N. In order to calculate the amount available, manures should be analyzed for both the ammonium and organic forms of N.

Soil testing. Soil sampling for less mobile nutrients including phosphorus (P) and potassium (K) should be done every 3 years, preferably at the same point in the rotation each time. The depth is usually 6 to 8 in. and must be consistent.

Forage harvests remove large amounts of K so it is critical to monitor the levels of this nutrient closely, since deficiencies can cut yields. However, excesses can cause imbalances in the feed ration for dry cows. Micronutrient levels—including copper and zinc—can also be important, particularly for their influence on the composition of the diet (Brock et al., 2005).

Crop scouting and plant analysis. Transient deficiencies of nutrients can impact crop performance, and even crops that look okay may be suffering from "hidden hunger". A regular program of monitoring both visual symptoms and nutrient levels in the plant tissue can help diagnose nutrients that either limit crop yield or pose risks of excess in the dairy diet.

Yield goal determination. Recommended rates of fertilizer often depend on the expected yield, or yield goal, of the crop to be grown.

Nutrient removal calculation. Forages in particular remove large amounts of nutrients.

Application

Placement of N. When N sources contain urea or ammonium, there is a risk of ammonia being lost to the air as a gas. However, when applied to an actively growing crop in cool temperatures, as is often the case with winter cereals, losses arising from urea topdress applications in early spring are small. Based on laboratory research conducted over 40 years ago, it has been concluded that ammonia losses from applied urea remain reasonably small at temperatures below 60 °F if the soil pH is 6.5 or less (Overdahl et al., 1991). Following first and second cut grass forage, however, alternative sources of N should be considered unless urea can be applied directly before irrigation or rain.

Band placement of P and K. Corn, cereals, and other crops respond most to P when their seedlings are young. Placement near the seed ensures access by the young seedlings, and placement in a band concentrates the nutrient to minimize fixation by the soil.

Timing of N. Being vulnerable to losses, N applied too early poses more risk of loss than when applied just before the period of rapid uptake. Alternatively, if controlled release or stabilized N technologies are used, the N can be applied prior to or at planting.

Management zones for variable rate application. On some farms, the same rate and blend of fertilizer is applied to all fields growing a particular crop. Soil test levels tend to vary strongly among fields, owing to differences in past manuring history.

Accurate rate metering. Maintaining and calibrating the machinery used for applying fertilizers is essential to delivering the right rate.

Minimizing Nutrient Losses

Nitrogen transport. Nitrogen can be lost by several pathways. Nitrate-N will be leached below the root zone if water moves down through the soil too quickly. When soils are saturated with water, nitrate can be denitrified to nitrous oxide or dinitrogen. Nitrous oxide is considered a potent greenhouse gas and a depletor of stratospheric ozone. Ammonium forms of N can be lost as ammonia gas to the air.

Phosphorus transport. Applying P at rates that balance removal is an important aspect of minimizing losses, but not the only one. Most soils remain fertile when application rates balance removal, but some may require more or less than removal depending on the soil tendency to retain or release phosphate. In some areas, deep tillage may help reduce P losses. The use of a P index gives a relative ranking of the influence of all major source and transport factors influencing the loss of P (Sharpley et al., 2003). Its use gives the best assurance for protection of water quality. Specific indexes, with software to facilitate calculation, are available for most states and provinces. BC

Dr. Bruulsema is PPI Northeast Region Director, located at Guelph, Ontario; e-mail: Tom.Bruulsema@ppi-ppic.org.

To view a chart listing fertilizer BMPs for this region, plus additional information and references, visit the PPI website: ***>www.ppi-ppic.org<***.

References

Brock, E., Q.M. Ketterings, and M. McBride, 2005. Copper and zinc accumulation in manured soils. What's Cropping Up? 15(5): 5-7. http://nmsp.css.cornell.edu/publications/articles/extension/cuzn2005.pdf

Overdahl, Curtis J., George W. Rehm, and Harvey L. Meredith. 1991. Fertilizer Urea. University of Minnesota Extension Service. http://www.extension.umn.edu/distribution/cropsystems/DC0636.html

Sharpley, A.N., J.L. Weld, D.B. Beegle, P.J.A. Kleinman, W.J. Gburek, P.A. Moore, Jr., and G. Mullins. 2003. Development of phosphorus indices for nutrient management planning strategies in the United States. J. Soil Water Conservation 58(3):137-152.

Best Management Practices for Profitable Fertilization of Potatoes

By Rob Mikkelsen

Because of the intensive nature of potato production, considerable work has been done to determine the optimum techniques to manage the crop and nutrients. This article looks at fertilizer best management practices (BMPs) for potatoes.

Potatoes managed for maximum productivity have a high demand on soil nutrients. Significant quantities of nutrients are accumulated in the tops and are removed from the field in the harvested tubers (**Table 1**). Since potatoes are commonly grown on sandy-textured soils, additional challenges for nutrient management are present.

Potatoes grown for processing are valued for yield, size, and also for dry matter content (measured by specific gravity). As the specific gravity increases, the water content of the potato decreases, improving the frying properties and flavor. Management factors, including fertility decisions, will influence potato yield, quality, and storage properties. Potato growth is classified into four distinct growth phases (**Figure 1**). The exact timing of these growth phases depends on many environmental and management factors that vary between locations and cultivars. However, these distinct stages of growth need to be considered when managing the crop.

Table 1. Typical nutrient accumulation and removal in Russet potatoes in a 500 cwt/A crop (lb/A).

Nutrient	Potato vines	Removed in tubers	Total accumulation
Nitrogen (N)	139	214	353
Phosphorus (P)[1]	11	29	40
Potassium (K)[2]	275	240	515
Calcium (Ca)	43	7	51
Magnesium (Mg)	25	15	40
Sulfur (S)	12	22	34

Source: Oregon State Univ. Potato Information Exchange. 2004. Also personal communication, Dr. Don Horneck, Oregon State Univ.

[1]To convert P to P_2O_5, multiply by 2.29

[2]To convert K to K_2O, multiply by 1.2

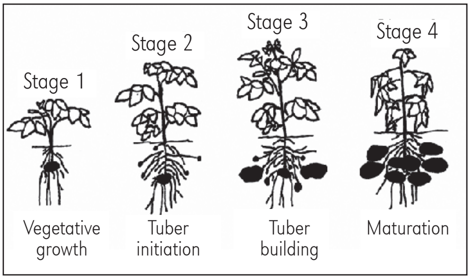


Figure 1. Major stages of growth and development of potatoes. The nutrient requirement of the developing potato changes during the growing season.

The maturity class and growing season length are two primary factors determining potato nutrient requirements. Short-season, early maturing (determinate) potatoes generally have a high and intense nutrient demand during the vegetative and tuber initiation stages. Long-season potatoes (indeterminate) have a longer period of nutrient uptake. The specific fertilization strategy must be adjusted for the different varieties and maturity classes or poor results will occur.

Nutrient Management

For potatoes, either deficient or excessive plant nutrition can reduce tuber bulking and quality. Nutrient deficiencies may limit the leaf canopy growth and its duration, resulting in reduced carbohydrate production and tuber growth. Maintaining healthy leaves is a key to producing high yields. However, excessive nutrient applications may cause nutrient imbalances or over-stimulate vegetative growth at the expense of tuber production. Some nutrients, such as S, may also have indirect yield benefits by reducing tuber disease.

Proper N management is one of the most important factors required to obtain high yields of excellent quality potatoes. An adequate early season N supply is important to support vegetative growth, but excessive soil N later in the season will suppress tuber initiation, reduce yields, and decrease the specific gravity in some cultivars. Excess soil N late in the season can delay maturity of the tubers and result in poor skin set, which harms the tuber quality and storage properties.

Potatoes are a shallow-rooted crop, generally growing on sandy, well-drained soils. These soil conditions frequently make water and N management difficult since nitrate is susceptible to leaching losses. On these sandy soils, it is recommended that potatoes receive split applications of N during the growing season. This involves applying some of the total N requirement prior to planting and applying the remainder during the season with side-dress applications or through the irrigation system. The period of highest N demand varies by potato variety and is related to cultivar characteristics such as root density and time to maturity. Use of petiole analysis during the growing season allows producers to determine the N status of the crop and respond in a timely manner with appropriate nutrients.

Roots absorb phosphate ions only when they are dissolved in the soil water. Phosphorus deficiencies can occur even in soils with abundant available P if drought, low temperatures, or disease interfere with P diffusion to the root through the soil solution or otherwise stunt normal root development and function. Proper irrigation management and scheduling is critical for potato development and utilization of applied nutrients.

Commonly available P fertilizer sources are equally useful for potato nutrition. The selection of a particular P fertilizer is generally based on grower preference, price, and compatibility with application equipment. Recent research suggests that modifications to P fertilizer, such as polymer additives, humic substances, and coatings may be beneficial in improving P uptake and potato production.

Potatoes require large amounts of soil K, since this nutrient is crucial to metabolic functions such as the movement of sugars from the leaves to the tubers and the transformation of sugar into potato starch. Potassium deficiencies reduce the yield, size, and quality of the potato crop. A lack of adequate soil K is also associated with low specific gravity in potatoes.

Potassium deficiencies impair the crop's resistance to diseases and its ability to tolerate stresses such as drought and frost. Applying K fertilizer with a broadcast application prior to planting is most commonly recommended. If the K is band-applied, the rates should be kept below 50 lb K_2O/A to avoid any salt injury to the developing sprouts.

Pre-season soil sampling and analysis can provide essential information on the starting point and residual fertility related to the growing conditions for the potato crop. In-season soil analysis can also provide information useful for monitoring nutrient availability along with plant tissue testing.

Potato petioles are frequently sampled during the growing season to monitor the plant nutrient status. Petiole analysis can be done for all of the essential nutrients, but nitrate determination is the most common test. Petiole P concentrations are also used to measure the P status during the growing season. BC

Dr. Mikkelsen is PPI West Region Director, located at Davis, California; e-mail: rmikkelsen@ppi-far.org.

To view a chart listing fertilizer BMPs for the Northwest U.S., plus additional information and references, visit the PPI website: ***>www.ppi-ppic.org<***.

Fertilizer BMPs for the Northern Great Plains — How Do You Measure Up?

By Adrian Johnston

Farmers in the Northern Great Plains have implemented soil conservation practices to a degree that exceeds any other resource conservation activity in North America. Erosion has been reduced and moisture conservation and soils improved, increasing yields and whole farm economics. Now fertilizer best management practices (BMPs) need evaluation.

The main science-based tool we have to make estimates of soil nutrient supply on agricultural lands in the Northern Great Plains is soil testing. The soil testing process is based on soil samples being taken from representative areas in a field, analyzed using a chemical extraction appropriate for the soils in the region, and either correlated with plant nutrient uptake or calibrated with crop yield (Karamanos, 2003). Resulting fertilizer recommendations would be based on how a particular crop responded to a nutrient, using the average response from a multi-year and multi-site data set.

In semiarid agriculture, water is one of the major driving variables in crop yields. Nutrients also play an important role in improving the use of water by crops by increasing the amount of yield per unit of water used (Zentner et al., 2002). As a result, a field-specific yield goal is determined based on available soil moisture at seeding, precipitation probabilities for the region, crop water use, and soil residual nutrient levels. For nitrogen (N) specifically, the result is a minimum fertilizer recommendation followed by in-season crop monitoring at critical growth stages based on plant density, tiller formation, and spikelets per head. If yield estimates indicate a larger yield than fertilized for originally, additional N can be top-dressed before the crop becomes too advanced.

For phosphorus (P) and potassium (K), the year-to-year variation in plant-available soil supply is minor, and annual application based on a balance between soil test levels and crop requirements can avoid depletion or over-application.

Soil testing and use of crop nutrient uptake and removal information are important guides to ensuring that balance among soil-available nutrients plus applied fertilizer prevents nutrient deficiencies from limiting crop yields or some nutrients from being used inefficiently. An example of proper nutrient balance is illustrated in a winter wheat study conducted in Manitoba (**Table 1**). Soil testing indicated a deficiency of both N and P at this site. The P fertilizer was seed row-applied at planting, and the N spring broadcast as ammonium nitrate (NH_4NO_3) immediately prior to crop growth and N uptake. While application of N alone increased yields more than P alone, it was the balance of N + P that optimized the crop response. To maximize yields using the highest rate of N, the highest rate of P was also required. Similar examples

Table 1. Winter wheat response to fertilizer N and P application in Manitoba.

P_2O_5 rate, lb/A	N rate, lb/A 0	110	N efficiency
	-- Grain yield, bu/A --		lb grain/lb N
0	15	48	26.2
20	17	55	30.0
40	20	65	35.5

Source: Grant et al. 1985. Can. J. Soil Sci. 65: 621-628.

Table 2. Barley yield response to tillage and fertilizer urea placement.

	Conventional tillage	Zero tillage
	- - - Grain yield, bu/A - - -	
Broadcast, 65 lb N/A	62	45
Band, 65 lb N/A	64	65

Source: Malhi and Nyborg. 1992. Soil Tillage Res. 23: 193-197.

can be shown with N and sulfur (S) on canola.

Deep banding of fertilizer N is a very important BMP, widely used in the region. It has been shown to reduce per-unit production costs by increasing fertilizer efficiency. Seeding system also plays an important role on the impact of fertilizer placement. When incorporated with tillage, barley showed a similar response to broadcast and in-soil band application (**Table 2**). However, when the broadcast urea was applied on the residue-covered surface of a zero tillage field and not incorporated, grain yield was reduced by 31% relative to an in-soil band.

A project on heavy clay soils in Manitoba found that fall N application timing had less of an impact on crop yield response in upland landscape positions than lowland areas. Even though all of the urea N treatments were banded in this study, delaying the N application timing improved the crop response with the wetter soil conditions in the lowland areas of the field.

Crops grown with proper nutrition are also playing a major role in building soil organic matter. Increased crop residue production leads to increased residue incorporation to build soil organic matter levels. In long-term rotation studies across the semiarid region of western Canada, moderate applications of N and P fertilizer have been shown to increase surface soil organic matter content (**Table 3**).

In many instances where no-till field management has been adopted, soil erosion and water runoff have been significantly reduced. In Quebec, an on-farm program using forage buffer strips adjacent to surface water bodies found that total runoff of water was reduced by 48%, soil particles in the water were reduced by 90%, and nutrient losses were reduced by 69% for total N and 86% for total P.

Table 3. Influence of fertilization on the average organic C and total N concentration in surface soils from long-term continuous wheat rotations on the Canadian Prairies.

Location	Fertilizer	Organic C, %	Total N, %
Swift Current			
(Brown soils)	P	1.78	0.197
	N + P	2.15	0.226
Lethbridge			
(Dark Brown soils)	None	1.62	0.149
	N + P	1.88	0.171
Indian Head			
(Black soils)	None	2.48	0.198
	N + P	2.59	0.223

Sources: Biederbeck et al. 1984. Can. J. Soil Sci. 64: 355-367.
Campbell et al. 1990. Agric. & Agri-Food Canada Publ. No. 1841/E.
Janzen. 1987. Canada J. Soil Sci. 67:165-174.

Many farmers in the Northern Great Plains have demonstrated a rapid adoption of fertilizer BMPs. Soil testing, realistic yield goals based on available water, balanced fertilizer application, in-soil banding of fertilizer at seeding, and use of no-till seeding systems all demonstrate excellent progress. Continued evaluation of new fertilizer management practices is critical. BC

Dr. Johnston is PPI/PPIC Northern Great Plains Region Director, located in Saskatoon, Saskatchewan; e-mail: ajohnston@ppi-ppic.org.

To view a chart listing fertilizer BMPs for this region, plus additional information and references, visit the PPI website: ***>www.ppi-ppic.org<***.

References

Karamanos, R.E. 2003. Soil testing – the art of the science. p. 11-16. *In* Proceedings of the Western Canada Agronomy Workshop. Canadian Fertilizer Institute, Ottawa, ON.

Zentner, R.P., D.D. Wall, C.N. Nagy, E.G. Smith, D.L. Young, P.R. Miller, C.A. Campbell, B.G. McConkey, S.A. Brandt, G.P. Lafond, A.M. Johnston, and D.A. Derksen. 2002. Economics of Crop Diversification and Soil Tillage Opportunities in the Canadian Prairies. Agron. J. 94: 216-230.

NORTHCENTRAL

Fertilizer Nitrogen BMPs for Corn in the Northcentral Region

By Scott Murrell

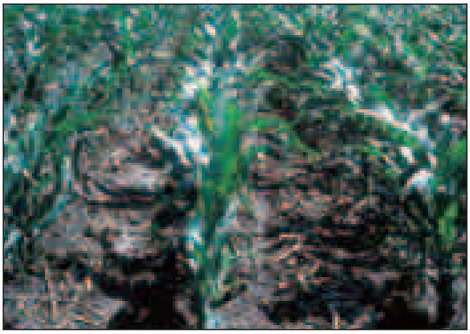
This article presents a summary of more than 30 university Extension publications in the Northcentral Region where best management practices (BMPs) are defined for nitrogen (N) use on corn. The information presented here represents BMPs common to many, and sometimes all, states in the region.

The BMPs discussed here are organized under the categories of right form, right rate, right time, and right place.

Right Form

Fall applications. Use ammoniacal or ammonium forms of N. Many consider anhydrous ammonia to be the best form to minimize loss of nitrate (NO_3^-) because it has the slowest rate of nitrification. Good chances exist that a nitrification inhibitor will provide benefits on poorly drained soils and soils with higher moisture levels near the surface when N is not applied in excess. Fall applications with a nitrification inhibitor risk not being as effective as the same rate of N applied in the spring. Use of urea is acceptable in drier climates, such as parts of western Minnesota and South Dakota, if it is incorporated soon after application on soils with lower leaching and denitrification loss potentials. A urease inhibitor may provide benefits when incorporated or 0.2 to 0.5 in. of rain does not occur within 2 to 3 days after application. Forms containing NO_3^- are not recommended.

Pre-plant or side-dress applications. On sandy soils, anhydrous ammonia performs best and forms containing NO_3^- should be avoided because of chances of leaching losses. On medium and fine textured soils, ammoniacal and ammonium forms, such as anhydrous ammonia and urea, reduce chances of NO_3^- loss. A nitrification inhibitor will usually provide benefits with pre-



plant and early side-dress applications on poorly drained soils when N is not applied in excess. Fair chances exist for silt loams and coarser textured soils. A urease inhibitor can provide benefits when incorporation of urea or urea ammonium nitrate (UAN) is not possible within 2 to 3 days after application.

Right Rate

Setting realistic yield goals. For recommendations using a yield goal approach, use the average yield of the previous 5 year production levels of a given crop, then add a small percentage increase to account for a possibly higher, future attainable yield potential. Abnormally low yields should be excluded from the average.

Many states in the Northcentral Region have shifted N recommendations from a yield goal-based approach to methods that no longer consider yield levels. This change has occurred because of the lack of an observed relationship between economically optimum N rates and yield, analyzed across many site years of data across several states. This approach averages several factors in an N recommendation model. Other states are currently retaining yield goal-based recommendations, making model parameters more explicit and changeable by the user.

Soil nitrate tests. A variety of tests are available and either account for the NO_3 already present in the soil or combine current NO_3 levels with estimates of future N mineralization. Use of the tests and interpretation of the results are state-specific.

Previous legume crops. Legumes should be credited or consideration given to the effects of legumes on corn response to applied N. Second year effects should be considered for manure and alfalfa.

Accounting for all N sources. Record location, rate, and nutrient concentration of applied manure and/or biosolids. Include N applied in other fertilizers and applied at other times during the season.

In-season assessment. Look for N deficiency symptoms. Also, a chlorophyll meter can be used if a reference strip has been left in the field. Reference strips are those where N is known to be adequate. If a need is indicated, supplemental N applications can be made. These may be side-dress or aerial applications, fertigation, or applications with high clearance equipment.

Post-season assessment. Measuring earleaf N concentrations and/or using the stalk NO_3 test can provide indications of the sufficiency of N for the crop grown. These assessments can be used to alter future management practices.

Right Time

Fall applications. Apply ammoniacal or ammonium forms of N only when soil temperatures are sustained below the critical 50 °F temperature. Do not apply N in the fall on sandy soils or soils with a higher permeability. Fall applications are not well suited to fine-textured, poorly drained soils. Fall applications run a risk of being less effective in increasing crop yields than spring applications, but work best on medium-textured, well-drained soils where N loss through leaching and denitrification is usually low.

Pre-plant or side-dress applications. Use split applications on sandy soils or fine-textured, poorly-drained soils. Side-dress applications are usually best on irrigated, sandy, low cation exchange capacity (CEC) soils. Pre-plant applications alone work best on medium and heavier textured soils except under conditions of excessive early season rainfall. Side-dress applications should be made no later than about 6 weeks after planting, or when corn is 6 to 12 in. tall.

Post side-dress applications. If a required side-dress application has been missed, an emergency rescue aerial application of urea can be used. Aerial applications of N solutions are not recommended.

Right Place

Anhydrous ammonia. Inject 6 to10 in. deep on friable, moist soil. Free ammonia can damage seedlings. Closure of the slot in the soil made by the applicator is needed to minimize volatilization loss.

Aqua ammonia and low-pressure solutions. Inject 2 to 4 in. deep on friable, moist soil. Closure of the slot in the soil made by the applicator is needed to minimize volatilization loss.

Urea and urea ammonium nitrate. Inject 4 in. deep, or surface apply and incorporate. Higher pH soils cause higher losses of N through ammonia volatilization. Higher losses can also occur if urea is surface applied on moist soils under windy conditions or following unincorporated lime applications. Post-emergence applications that are broadcast or sprayed may cause plant injury. Urea should not be applied with the seed. After emergence, UAN should be applied between rows to avoid leaf burn, preferably dribbled or sprayed in surface bands to reduce contact with the urease enzyme in both the soil and plant residue.

Ammonium and/or nitrate forms. These forms can be left on the surface, incorporated, or injected. Surface applications without incorporation should be done only where there is low risk of runoff. Surface applications of ammonium forms on calcareous soils can result in N losses through ammonia volatilization if left unincorporated.

Table 1. Maximum recommended nutrient rates of starter fertilizer to be applied in direct contact with corn seed during planting at a row spacing of 30 in. Urea, UAN, and ammonium thiosulfate are not recommended for placement with the seed.

State	Max. rate of $N+K_2O$, lb/A	Notes
Iowa	10	Soils with adequate moisture, not sandy.
	5	Sandy and/or dry soils.
Illinois	13-16	Rate range is for normal moisture conditions. In excessively dry spring conditions, these rates may be too high.
Indiana	8	Soils with CEC > 8
	5	Soils with CEC < 7
Minnesota	12-16	Information calculated from data in Table 5 (in the reference) for the 10 gal/A rate, assuming 11.2, 10.3, and 11.65 lb/gal densities for 7-21-7, 4-10-10, and 10-34-0, respectively. Rates are based on adequate moisture. If soils are dry at planting, some seed damage can occur at these rates.
South Dakota	10	Medium and finer textured soils with adequate moisture.
	5	For dry and/or sandy soils.
Wisconsin	10	For sources other than urea.

Banding during planting (starter). Some N applied with or near the seed at planting provides a small supply of strategically-placed N early in the season. This can be especially important when the primary N application is banded between the rows. Plant root growth early in the season may not be extensive enough to reach this banded N, increasing the reliance on the N applied near the seed during planting. Placement in direct contact with seed limits the rates of N that can be applied (**Table 1**). It also carries higher risk of salt damage than placement a small distance from the seed, such as 2 in. to the side and 2 in. below (2x2).

Band applications other than starter. Fertilizer N applied in bands can be applied mid-row as far apart as every other row.

Summary

The BMPs provided here for N use on corn represent general approaches used by many states in the Northcentral Region. Recommendations may vary for specific locations where more specialized BMPs exist.

For more detailed information and references pertaining to the BMPs described here, visit the Northcentral Region website at >**www.ppi-ppic.org/northcentral**<. The website also has a similar summary of BMPs outlined for phosphorus and potassium in corn production in the Northcentral Region.

Dr. Murrell is PPI Northcentral Director, located at Woodbury, Minnesota; e-mail: smurrell@ppi-far.org.

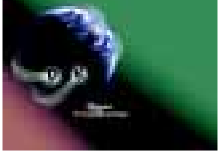
TOOLBOX

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 (P) and potassium (K) nutrient additions are keeping up with removal by crops.

PKalc and other programs can be accessed for free at:

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



International Section

NORTHWEST CHINA

Sustaining Higher Alfalfa Yields in Inner Mongolia

By Duan Yu, Tuo Debao, Zhao Peiyi, and Li Huanchun

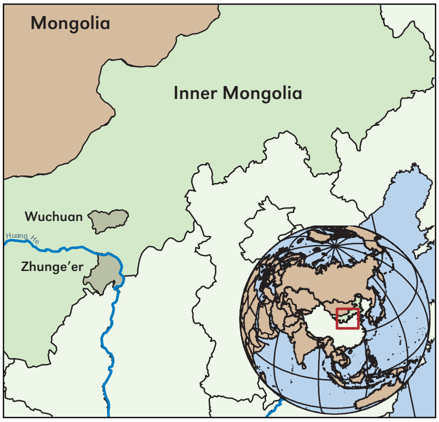
The fact that forage crops in Inner Mongolia receive little, if any, fertilizer input is highly evident in the face of general declines in productivity, crop quality, and soil quality. The region's land resource is of great importance to the food production goals of China. The identification of balanced nutrient strategies is an integral part of creating a revitalized forage production system.

Among the biggest challenges faced by the Inner Mongolia Autonomous Region (IMAR) are improving fragile range land ecosystems, increasing productivity in grazed and fodder producing systems, and strengthening crop management to meet local challenges (usually drought). The autonomous region is well known for its expansive range lands, estimated at about 87 million hectares (M ha) in 2001, which represents over 73% of total area in IMAR, and about 22% of all grasslands within China. IMAR also has a large cultivated area at 5.8 M ha, but its low crop index of 0.7 means that 30% of sown areas are unharvestable due to adverse conditions such as drought. Barren fields are a source of repeated dust storms, resulting in severe soil erosion events causing great environmental and economic loss.

IMAR is gradually increasing its land use efficiency through a steady, government-supported conversion of less productive arable lands to grasslands or forestry. By the end of 2003, 1.5 M ha of arable land has been returned to various forms of forest and grassland reserves in IMAR. The region is also steadily retiring its degraded grazing/pasture lands and establishing responsible management systems for those forage lands identified as still having good production potential. This process is imperative and is in harmony with the nation's strategy to improve its managed ecosystems. Traditionally, managed forage crops receive little to no fertilizer inputs. As such, it is a low value, environmentally degrading system.

Improved forage crops or seeded grasses are required to reduce the stress caused by the current numbers of livestock. The introduction of highly productive grass varieties along with proper fertilizer management will be important for sustained success. No doubt forage crop production will con-

The Inner Mongolia Autonomous Region has vast range lands.



Site	pH	OM	Ca	Mg	K	Ca/Mg	Mg/K	N	P	S	B	Cu	Fe	Mn	Zn
		- % -	------ mg/L ------					-------------------- mg/L --------------------							
Zhunge'er	8.4	0.2	1,603	111	74	14.4	1.5	3.0	13.7	1.8	2.1	0.7	6.4	6.8	1.7
Wuchuan	8.5	1.0	2,950	166	78	17.8	2.1	47.8	18.4	2.4	3.2	2.0	10.7	8.5	1.4

Table 1. Soil test results of field sites in Zhunge'er and Wuchuan counties, Inner Mongolia.

tinue as a prominent agricultural activity in IMAR. Recent forecasts indicate that Chinese farmers will expand the numbers of beef animals by 4.5% to 68.6 M head in 2006, matching a similar increase in 2005.

This research demonstrates the impact of balanced fertilizer use on alfalfa production. Success will not only entrench a large economic driver, but also an effective means of protecting the region's agro-ecology.

Field experiments were conducted in Zhunge'er and Wuchuan counties in 2004 and 2005. Soils at these sites had deep plough layers, were sandy loam in texture, but had poor fertility (**Table 1**). These soils are calcareous, high in available calcium (Ca) and magnesium (Mg), with moderate potassium (K) availability, and low nitrogen (N) and phosphorus (P) fertility. The study sites used 30 m^2 plots (7.5 m x 4 m), randomly arranged to receive urea, triple superphosphate, and potassium chloride (KCl) fertilizers prior to seeding. Fertilizers were applied as a band 20 cm below the surface.

In Wuchuan, alfalfa was sown in mid-May and first harvested in mid-September. In Zhunge'er, alfalfa was sown in mid-June and first harvested in mid-September. An "optimum" fertilizer treatment of 45-60-45 kg N-P_2O_5-K_2O/ha was set for both sites. This recommendation was a combined result of soil test interpretation and regional nutrient recommendations for other crops. Three omission plots were also included to quantify the relative effects of excluding N, P, and K from the optimum. A second cut was harvested from both sites in 2005. The vast majority of cultivated forages in IMAR are grown under rainfed conditions.

Results from the nutrient omission plots suggest large benefits at both sites from a one-time, balanced application of fertilizer (**Table 2**). First cut yields at Zhunge'er seemed more affected by nutrient omission than at Wuchuan. Regardless, the omission of K fertilizer had the greatest impact on first cut dry matter (DM) production at either location in the year of stand establishment. Yield gaps caused by K omission ranged between 1.0 t/ha (-28%) in Wuchuan to 1.5 t/ha (-44%) in Zhunge'er. Local economics placed the average value:cost ratio for K fertilizer at 10:1 (data not provided). Omission of N and P resulted in DM losses of 0.6 and 0.8 t/ha at Zhunge'er, and 0.3 t/ha each at Wuchuan.

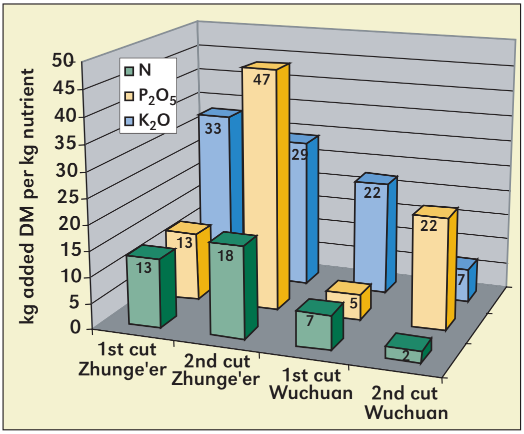
Production during the second cut was considerably higher at both sites, but production at Zhunge'er was especially improved. Yield gaps still existed between treatments. However, DM yield responses indicated that the effect of omitting P was now most significant. Thus, yield gaps due to N, P, and K omis-

Table 2. Rainfed alfalfa yields in Zhunge'er and Wuchuan counties (2004-2005).

Dry matter yield, t/ha	Zhunge'er NPK†	Zhunge'er - N	Zhunge'er - P	Zhunge'er - K	Wuchuan NPK†	Wuchuan - N	Wuchuan - P	Wuchuan - K
1st cut	3.4	2.8	2.6	1.9	3.6	3.3	3.3	2.6
2nd cut	11.5	10.7	8.7	10.2	5.8	5.7	4.5	5.5
Total	14.9	13.5	11.3	12.1	9.4	9.0	7.8	8.1

† NPK = 45-60-45 kg N-P_2O_5-K_2O/ha

Figure 1. Contribution of N, P, and K towards added alfalfa dry matter production.



sion were 0.8 t/ha (-7%), 2.8 t/ha (-24%), and 1.3 t/ha (-11%) at Zhunge'er. In Wuchuan, the gaps were 0.1 t/ha (-2%), 1.3 t/ha (-22%), and 0.3 t/ha (-5%). This trend was similar for the combined yield totals since the second cut had large influence on total production figures. Dry matter contributions per unit nutrient are provided for each cut in **Figure 1**.

Conclusions

The present productivity of grasslands in IMAR is not capable of sustaining the intensity of animal husbandry and will certainly not support any future plans for expansion as a means to inject much needed cash into the region. Alfalfa stands rarely thrive and common practice without fertilization typically results in a short-lived stand with low productivity. Application of fertilizers promotes growth and will prolong stand longevity. In addition, increased plant and root density resulting from fertilizer application increases protective ground cover and reduces the severity of wind erosion events, effectively preventing desertification. Under the conditions of this study, nutrient omission plots suggest significant initial contributions to dry matter production from both K and P fertilizers. The advantage gained from applied P became especially evident with time. The research suggests that stand establishment and growth can be enhanced through the implementation of balanced fertilization. BC

Mr. Duan Yu of Inner Mongolia Academy of Agricultural and Animal Husbandry Sciences observes the effect of balanced fertilization on alfalfa growth.

Mr. Duan is Associate Professor, Mr. Tuo is Professor, Mr. Zhao is Associate Professor, and Ms. Li is Assistant Professor, all with Plant Nutrition and Analysis Institute, Inner Mongolia Academy of Agricultural and Animal Husbandry Sciences, China; e-mail: yduan@ppi.caas.ac.cn.

World Congress of Soil Science Set for July 9-15

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

Site-Specific Nutrient Management in Mandarin Orchards

By A.K. Srivastava, Shyam Singh, and K.N. Tiwari

Site-specific nutrient management (SSNM) can help tailor fertilizer applications for individual orchards and begin to address a more complex problem of wide variation in fruit yield within orchards.

India has 320,000 ha of mandarin orchards producing 2.07 million metric tons (M t) of fruit annually. Although orchard productivity is highly variable within space and time, the average productivity per planted area of about 6 t/ha is obviously low if compared to the international average of 30 to 35 t/ha. A major constraint is inadequate and imbalanced nutrient use. The objective of this research is to narrow the gap in productivity by adopting principles of SSNM.

The study included two distinct yet representative soil types. Site 1 had a relatively shallow soil profile classified as a Typic Ustorthent (Entisol), while Site 2 was a Vertisol with a deeper soil profile classified as a Typic Haplustert (**Table 1**). These soil types are both derived from basaltic parent material with typical soil profiles predominantly rich in expanding-type, 2:1 montmorillonitic clay minerals characteristic of the sub-humid tropical climate of central India. The Vertisol at Site 2 had intersecting slickensides strongly expressed within the 52 cm to 1.48 m depth, an indication of significant shrink and swell activity.

Established orchards were 12-years old at Site 1 and 8-years old at Site 2. Plant to plant and row to row distances were 6 m. Both orchards used a scion of Nagpur mandarin (*Citrus reticulata Blanco*) budded on rough lemon rootstock (*Citrus jambhiri Lush*). A total of 16 treatments were applied based on soil analysis and the principles of SSNM (**Table 2**).

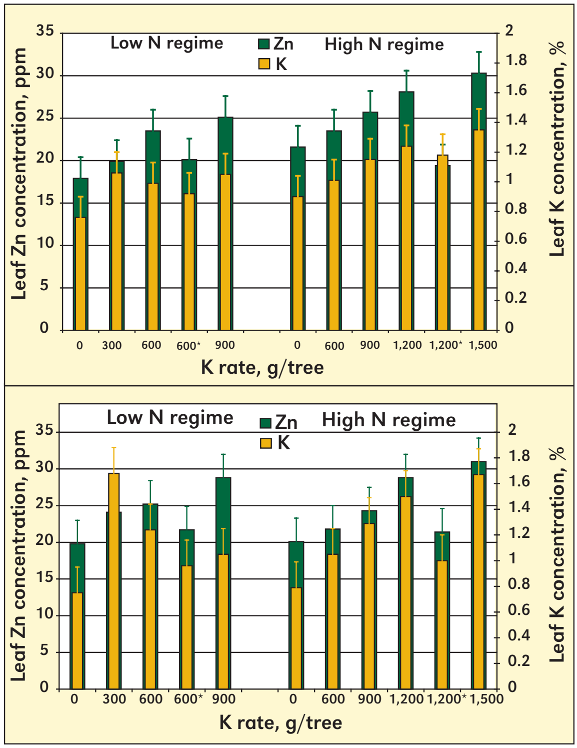
Two levels of input intensity were incorporated in the design based on a high and low nitrogen (N) rate. These treatments were replicated four times in a randomized block design. Timing of fertilizer applications were kept the same at both sites. Nitrogen was applied in the months of April, August, and October; phosphorus (P) and potassium (K) were applied in August and October. Two seasons of data collection included measurements of tree canopy growth, fruit yield and quality, leaf nutrient concentrations, and a cost:benefit analysis. Only the effective treatments and the current recommendation (CR) are discussed in this article.

Significant changes in leaf nutrient

Table 1. Soil physiochemical characteristics and fertility for soil surface horizons.

	Site 1 Entisol	Site 2 Vertisol
pH	7.3	7.6
E.C., d/Sm	0.21	0.18
$CaCO_3$, g/kg	21.2	20.2
Texture, g/kg		
Sand	384.0	296.6
Silt	203.8	222.4
Clay	412.2	482.0
Available nutrients, mg/kg		
N	88.2	96.2
P	7.6	11.4
K	132.6	162.8
Fe	6.1	8.2
Mn	8.0	7.6
Cu	0.9	1.2
Zn	0.7	0.8

Figure 1. Influence of K rate and micronutrient input on leaf K and Zn concentration under two nutrient input regimes. Asterisk (*) indicates no micronutrient input.



concentrations, expressed as parts per million (ppm), occurred in response to fertilization. Micronutrient inputs particularly affected zinc (Zn) concentrations of leaves and in some cases elevated leaf N, P, and K concentrations. Application of K increased leaf Zn concentrations irrespective of soil-type or whether any micronutrient was included in the treatment (**Figure 1**). However, the effect of K was greatest when co-applied with the micronutrients, and the effect increased as K supply increased. Hence, K application improved the efficacy of soil Zn and applied Zn, a result of similar metabolic pathways during the course of Zn absorption.

Canopy and fruit growth response differed between sites. The more mature trees at Site 1 responded more favorably to the more input intensive regimes. Differences between high and low N regimes were much less apparent at Site 2. Thus, at Site 1, T_9 and T_{10} registered the highest increases in canopy volume over initial measurements and T_{11} produced a comparable result (**Table 3**).

These treatments provided the highest levels of N, P, micronutrient, and secondary nutrient fertility plus either 600, 900, or 1,200 g K_2O/ha. Significant yield responses to fertilization followed responses observed in leaf nutrient concentrations. Fruit yield response to micronutrients was highly evident at both sites under either the high or low input regimes. Yield failed to respond to K application beyond 600 g K_2O/tree under the high input at both sites. However, a differential response to K was noted between sites under the set of low N input treatments, as Site 1 responded up to 900 g K_2O/tree while yield at Site 2 reached a plateau at 300 g K_2O/tree. Highest fruit yields of 14.7 t/ha (52.7 kg/tree) and 19.0 t/ha (68.3 kg/tree) were obtained with T_9 (Site 1) and T_6 (Site 2), respectively.

A cost/benefit analysis of T_9 at Site 1 produced a net return of Rs.58,569/ha (US$1,325/ha) or Rs.2.12 per rupee invested in fertilizers and other inputs. At Site 2, T_6 produced a net return of Rs.46,260/ha (US$1,045/ha) or Rs.1.68 per rupee invested.

Table 2. Range of fertilizer treatments applied to both orchards.

	N	P_2O_5	K_2O	M_1[1]	S_1[2]
Current	----- Rate, g/tree -----				
Rec.	600	200	100	✘	✘
Low N					
T_1	600	400	600	✓	✓
T_2	600	200	600	✓	✓
T_3	600	0	600	✓	✓
T_4	600	600	600	✓	✓
T_5	600	400	0	✓	✓
T_6	600	400	300	✓	✓
T_7	600	400	600	✘	✘
T_8	600	400	900	✓	✓
High N					
T_9	1,200	600	600	✓	✓
T_{10}	1,200	600	900	✓	✓
T_{11}	1,200	600	1,200	✓	✓
T_{12}	1,200	600	1,500	✓	✓
T_{13}	1,200	600	0	✓	✓
T_{14}	1,200	600	1,200	✘	✓
T_{15}	1,200	600	1,200	✘	✘

[1] M_1 = 300 g each of $ZnSO_4$, $FeSO_4$, $MnSO_4$, and 100 g borax/tree;
[2] S_1 = 400 g $MgSO_4$/tree and 100 g elemental S/tree.

Table 3. Canopy volume and fruit yield response to fertilization (mean of 2 years).

Treatments	Site 1 Canopy[1] volume, m^3	Site 1 Fruit yield, kg/tree	Site 1 Fruit yield, t/ha	Site 2 Canopy[1] volume, m^3	Site 2 Fruit yield, kg/tree	Site 2 Fruit yield, t/ha
Current Rec.	3.5	31.5	8.7	3.0	53.75	14.9
Low N						
T_1	3.9	37.4	10.4	3.5	58.90	16.4
T_2	3.7	30.6	8.5	2.7	57.25	15.9
T_3	3.4	27.9	7.7	3.1	57.15	15.9
T_4	4.6	39.2	10.9	2.9	58.00	16.2
T_5	4.2	33.4	9.3	2.4	55.30	15.4
T_6	4.7	33.9	9.7	5.4	68.30	19.0
T_7	3.8	25.1	7.0	2.6	39.25	10.9
T_8	5.7	49.9	13.9	4.3	48.70	13.5
High N						
T_9	6.6	52.7	14.7	3.7	60.95	16.9
T_{10}	6.6	41.8	11.6	3.3	50.40	14.0
T_{11}	5.8	39.3	10.9	3.9	56.10	15.6
T_{12}	4.6	36.3	10.1	4.3	56.35	15.7
T_{13}	3.8	33.3	9.3	3.3	46.55	12.9
T_{14}	4.5	33.9	9.4	2.9	46.35	12.9
T_{15}	3.9	30.0	8.3	2.9	45.50	12.6
LSD (p=0.05)	1.2	8.0	2.2	1.0	8.10	2.2

[1] Expressed as increase over initial values

Table 4. Fruit quality response to fertilization (mean of 2 years).

Treatments	Site 1 Juice, %	Site 1 TSS, %	Site 1 Acidity, %	Site 2 Juice, %	Site 2 TSS, %	Site 2 Acidity, %
Current Rec.	44.0	8.6	0.57	43.1	8.5	0.68
Low N						
T_1	45.7	8.2	0.56	45.5	8.1	0.77
T_2	44.5	8.5	0.64	41.6	7.6	0.68
T_3	44.1	9.1	0.60	42.4	8.4	0.75
T_4	44.7	8.8	0.63	43.7	7.9	0.68
T_5	41.9	9.6	0.56	42.4	8.7	0.64
T_6	44.9	9.3	0.58	49.8	8.6	0.67
T_7	45.2	8.6	0.62	46.5	7.8	0.81
T_8	48.3	8.2	0.75	48.2	7.9	0.82
High N						
T_9	45.4	8.9	0.55	42.7	8.8	0.62
T_{10}	42.6	8.6	0.59	43.6	8.2	0.71
T_{11}	44.9	8.5	0.63	44.8	8.1	0.76
T_{12}	48.4	8.2	0.80	46.3	7.6	0.86
T_{13}	41.6	8.2	0.51	42.5	9.1	0.66
T_{14}	43.2	9.5	0.64	43.7	8.5	0.77
T_{15}	44.6	9.6	0.63	43.8	8.2	0.74
LSD (p=0.05)	3.1	0.5	0.09	3.2	0.6	0.08

Across sites, micronutrient and secondary nutrient application had little impact on juice content, total soluble solids (TSS), or fruit acidity (**Table 4**). However, both sites and input regimes demonstrated significant quality responses to K. Maximum fruit juice contents corresponded with conditions of high K fertility, as did fruit acidity. This latter observation suggests that K fertilization will play a role in influencing the time to fruit maturity since fruits with higher juice acidity take more time to attain the color break stage.

Total soluble solids showed a negative response to increased K application. Significant response to improved fertilization strategies over currently recommended doses of fertilizers warrants addressing nutrient requirements on a site-specific basis. BC

Dr. Srivastava is a Senior Scientist (Soil Science) at National Research Centre for Citrus, Maharashtra, India; e-mail: citrus9_ngp@sancharnet.in. Dr. Singh is Director at National Research Centre for Citrus. Dr. Tiwari is Director, PPI/PPIC-India Programme, Gurgaon, Haryana, India.

Measuring Corn Response to Fertilization in the Northern Pampas

By Pablo Prystupa, Flavio H. Gutiérrez Boem, Fernando Salvagiotti, Gustavo Ferraris, and Lucrecia Couretot

Phosphorus (P) and sulfur (S) responses were most prevalent and their application most critical to maintain optimal growth rates and higher corn grain yield. Increases have been related to higher grain number. Deficiencies of P and/or S reduced crop growth rate around flowering. Potassium (K) responses have not been observed in these high K testing soils.

The northern Pampas is the main corn production region in Argentina. Nitrogen (N) and P deficiencies are frequently observed in cereals grown in this region. Yield increases due to S addition are becoming increasingly common. This is especially true for soils with many years of continuous cropping, partial loss of soil surface horizons through erosion, and reduced organic matter contents. No responses to K fertilization are reported in grain crops, but continuous negative nutrient balances may cause this to change. It is important to periodically re-examine nutrient responses and deficiencies within the region.

Objectives of this study were: i) to determine corn response to P, S, and K fertilization; ii) to analyze the effects of P, S, and their interaction on mechanisms involved in yield determination of corn; and iii) to evaluate the effects of P and S fertilization on grain N, P, and S content.

Thirteen on-farm experiments were conducted during 2 years (7 during 2003/04 season, and 6 during 2004/05 season), on Argiudoll and Hapludoll soils in southern Santa Fe Province and northern Buenos Aires Province. Soil properties at each experimental site are provided in **Table 1**. Five treatments were arranged in a randomized complete block design with four replicates (**Table 2**). Phosphorus fertilizer (triple superphosphate) was placed in a band below and to the side of the seed, while S (gypsum) and K (potassium chloride) were broadcast. All treatments received 150 kg N/ha as urea. All fertilizers were applied at sowing. Other crop management followed current farmer technology.

Potassium addition did not affect grain yield. No significant differences were observed between $P_{30}S_{30}K_0$ and $P_{30}S_{30}K_{100}$ treatments at any experimental site. Soil exchangeable K at every site was high compared with critical values reported in the literature. These values usually vary between 110 and 200 parts per million (ppm) (Haby et al., 1990).

Most of the experiments showed yield increases. Yield increased significantly in 7, 4, and 2 sites due to the addition of P, S, or both, respectively. The average yield in-

Grain number per surface area is a major factor in corn yields.

Table 1. Soil characteristics at the experimental sites (0 to 20 cm depth), Argentina.

Site	Organic matter, %	Bray 1 P, ppm	Exchangeable K, ppm	pH	SO_4-S, ppm	SO_4-S, 0-60 cm, ppm
1	2.9	13.2	449	5.7	13.5	17.1
2	2.2	11.8	507	5.8	8.2	5.8
3	2.0	21.1	536	5.6	5.7	4.9
4	2.2	6.3	595	6.2	12.5	10.6
5	1.7	7.3	566	5.9	5.3	2.8
6	3.2	11.4	663	5.6	12.0	10.0
7	3.0	11.9	692	5.6	8.0	6.8
8	2.8	7.2	585	5.8	7.2	7.7
9	2.7	9.3	546	5.6	7.0	5.8
10	3.5	10.1	585	5.9	12.0	7.6
11	2.8	5.2	569	5.8	7.6	6.7
12	2.4	6.0	566	5.4	8.9	7.4
13	2.4	4.9	663	5.5	10.6	8.2

crease from P fertilization was 1,631 kg/ha (19% over the control). Mean yield increase due to S fertilization was 1,145 kg/ha (11% over the control). Phosphorus and S effects were additive, as no significant interaction was observed at any site. Yield increase due to S addition was not related to measured soil characteristics (i.e., sulfate concentration, soil organic matter content), management practices (i.e., previous crop, years from last pasture), or maximum yield achieved at the site.

In corn, like other cereal crops, grain yield is mainly determined by grain number per surface area (GN). Andrade (1995) has observed that grain number is strongly associated with the crop growth rate (CGR) during a 40-day period around flowering. Thus, when the crop suffers water or radiation stress during this period, the grain number is reduced due to a lower biomass accumulation rate. Similarly, we hypothesized that a P or S deficiency would reduce the crop growth rate during this period, and therefore, grain number and yield.

Table 2. Rates of P, S, and K applied (kg/ha) in each treatment.

Treatment	P	S	K
$P_0S_0K_0$	0	0	0
$P_0S_{30}K_0$	0	30	0
$P_{30}S_0K_0$	30	0	0
$P_{30}S_{30}K_0$	30	30	0
$P_{30}S_{30}K_{100}$	30	30	100

Grain yield was related to grain number: [Yield (kg/ha) = 3.05 GN (number/m^2) + 1,958; r^2 = 0.52]. Crop growth rate did not show a close relationship with grain number across sites (r^2=0.034), even when only data from treatments with high P and S availability was used (r^2=0.029). These results suggest that changes in grain number across sites could not be explained by variation in CGR. Since it may be possible that each hybrid had a different GN-CGR relationship, normalized GN and CGR values were calculated in order to avoid hybrid or site effects on this relationship. Normalized GN (GNn) was calculated by dividing the GN of each treatment by the average GN of the site. Normalized CGR (CGRn) was calculated by dividing the CGR of each treatment by the average CGR of the site. Normalized values varied around 1 and reflected variation due to fertilization treatments applied within each site. Analysis of these data found a relationship between GNn and CGRn (**Figure 1**). This association suggests that changes in GN due to P and S fertilization

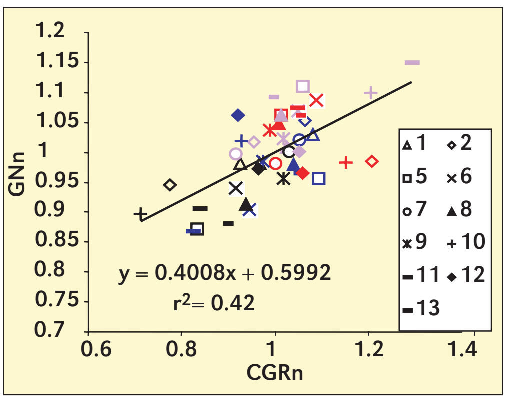


Figure 1. Relationship between normalized grain number (GNn) and normalized crop growth rate (CGRn). Symbol color denotes treatment: $P_0S_0K_0$ (black), $P_0S_{30}K_0$ (blue), $P_{30}S_0K_0$ (red), and $P_{30}S_{30}K_0$ (violet). Symbol shape denotes experimental site (see legend). Each point is the mean of four replications. Data from sites 3 and 4 were not determined.

Table 3. Concentration of N, P, and S in grain (mg/g), and N:S ratio. Range and mean values for all experimental sites for each treatment, Argentina.

	N			P			S			N:S		
	Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.
$P_0S_0K_0$	11.6	15.3	12.8	1.68	2.93	2.41	0.61	1.33	0.97	9.21	29.34	15.83
$P_0S_{30}K_0$	10.8	16.1	12.8	1.57	2.79	2.32	0.72	1.37	1.05	9.72	25.29	13.88
$P_{30}S_0K_0$	11.4	16.1	13.2	1.93	3.24	2.63	0.71	1.09	0.84	12.02	34.80	18.78
$P_{30}S_{30}K_0$	11.2	15.1	13.1	1.75	3.21	2.63	0.79	1.36	1.07	8.25	19.61	13.30

were in part explained by their effects on the CGR around flowering.

Nitrogen, P, and S concentration were determined in grain from the four treatments without K addition. Phosphorus fertilization increased N concentration in grain slightly (**Table 3**). Across all sites, N concentration increased by 3% (from 12.8 to 13.2 mg/g). Nitrogen exported with grain was 13 kg N/tonne of grain. This value was similar to the previously reported number of 14.5 kg N/tonne (INPOFOS, 1999).

Phosphorus fertilization increased P concentration in grain, regardless of soil P availability or crop response to P fertilization (**Table 3**). Across all sites and S treatments, P concentration increased by 11% (from 2.36 to 2.63 mg P/g). Phosphorus exported with grain was 2.5 kg P/tonne, a value slightly lower than the previously reported value of 3 kg P/tonne (INPOFOS, 1999). Phosphorus fertilization also affected S grain concentration at several sites, but effects were small and inconsistent (S concentration was higher, lower or remained unaffected). These variations were not related to yield response to P fertilization.

Sulfur fertilization increased S concentration in grain, while it did not affect N or P concentration. Thus the grain N:S ratio was also reduced (**Table 3**). The mean increase in S concentration, across all sites and P treatments, was 17% (from 0.90 to 1.06 mg S/g). The N:S ratio is associated with the proportion of S containing amino acids (i.e., cysteine, methionine) which are present within grain protein. These results suggest that S does not affect protein concentration, but modifies its composition. Sulfur exported from the grain of crops fertilized with S was 1 kg S/tonne, a value lower than the previously reported number of 2 kg S/tonne (INPOFOS, 1999).

These experiments showed evidence about the relevance of P and S deficiencies in corn production in the Pampas. On the other hand, K deficiencies have not been detected. Crop response to S fertilization was not related to soil or management variables. Yield increases due to S or P fertilization were associated with changes in the crop growth rate during the period around flowering. Grain P content increased with P fertilization. Sulfur fertilization increased S concentration in grain, but it did not affect N and P content. BC

Mr. Prystupa (email: prystupa@agro.uba.ar) and Dr. Gutiérrez Boem are with Facultad de Agronomía, University of Buenos Aires; Mr. Salvagiotti is with EEA INTA Oliveros, Santa Fe; Mr. Ferraris and Ms. Couretot are with EEA INTA Pergamino, Buenos Aires.

References

Andrade F. 1995. Field Crops Res. 41:1.12.

Haby, V.A., M.P. Ruselle, and E.O. Skogley. 1990. *In* R.L. Westerman (ed.) Soil testing and plant analysis. SSSA. Madison, WI. pp. 181-227.

INPOFOS. 1999. INPOFOS Cono Sur (PPI/PPIC) >http://www.inpofos.org/ppiweb/ltams.nsf<, accessed on 10/25/2005.

Towards a Site-Specific Nutrient Management Approach for Maize in Asia

By C. Witt, J.M. Pasuquin, and A. Dobermann

A new regional initiative has the goal of improving the productivity and profitability of maize in key agro-ecological zones of Southeast Asia through site-specific, integrated nutrient and crop management.

Maize is the second most important cereal crop in Asia, not only as a staple food, but also as a major component of feeds for the animal industry. The total area planted to maize in Southeast Asia is currently about 8.6 million hectares (M ha), with the largest areas in Indonesia (41%), the Philippines (29%), Thailand (13%), and Vietnam (12%). The growing demand in the region cannot be met despite the increase in domestic production and yield of maize in the last 15 years (**Figure 1**).

Indonesia's maize production and yield, for example, continue to increase. Yet the country imported more than 1 million metric tons (M t) of maize annually in the last 5 years. Average national yield in Indonesia, Thailand, and Vietnam is only 3 to 4 t/ha (2 t/ha in the Philippines) and knowledge on yield potential, exploitable yield gaps, and constraints to improving productivity at the field level is still limited.

We have therefore launched a new, 3-year project in collaboration with key research institutes in Indonesia, the Philippines, and Vietnam. Objectives

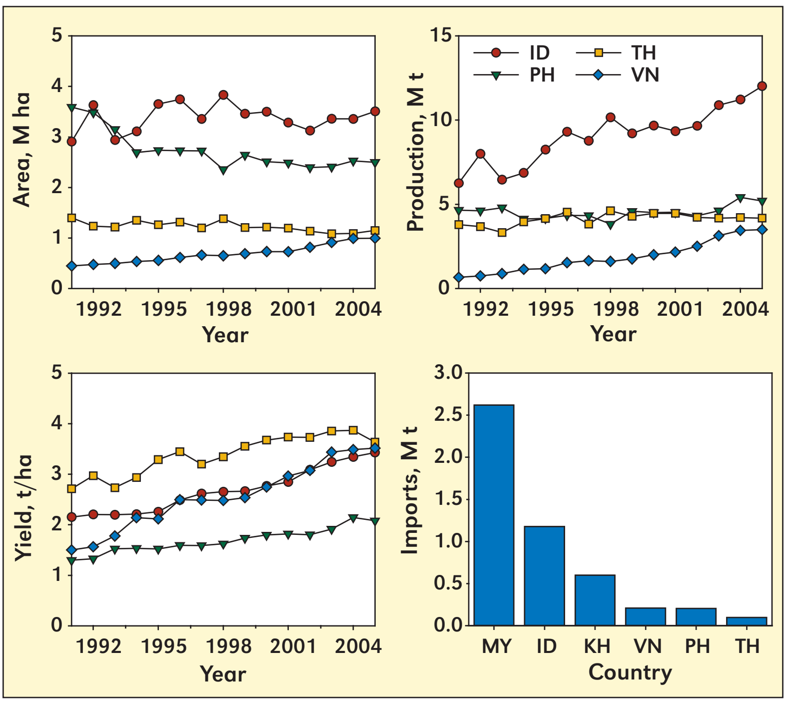
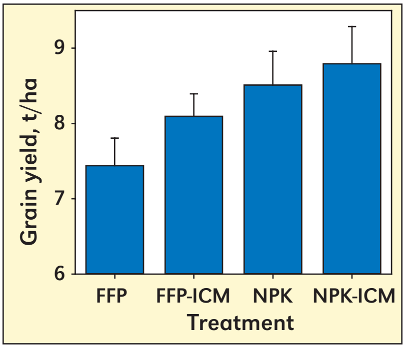


Figure 1. Area, production, and yield of maize in selected countries in Southeast Asia 1991-2005. Maize import data are the average of 2000-2004. Data source: FAOSTAT 2006 (www.fao.org). ID = Indonesia; KH = Cambodia; MY = Malaysia; PH = Philippines; TH = Thailand; VN = Vietnam.

Figure 2. Grain yield of hybrid maize in 30 farmers' fields at five key maize sites in Indonesia, 2004-2005. FFP = Farmers' Fertilizer Practice; NPK = treatment with ample application of fertilizer N, P and K; ICM = Improved Crop Management.



include: i) quantify and understand the yield potential of maize and ii) develop, evaluate, and disseminate site-specific nutrient management (SSNM) and best crop management practices for maize. The project currently supports a network of 120 on-farm experiments in these three countries. Treatments always include omission plots (-nitrogen [N], -phosphorus [P], and -potassium [K]) to estimate nutrient-limited yield, a fully-fertilized treatment with ample N, P, and K fertilizer to estimate attainable yield, and a farmers' fertilizer practice (FFP) plot to serve as a benchmark for comparison. In general and except for FFP, fertilizer N is applied in three relatively equal splits at crop establishment, and growth stages V5 to 6 and V7 to 8, all fertilizer P and K is applied together with the basal N dose, in some cases 50% of fertilizer K was applied with the last N application. Improved crop management (ICM) plots were established at all sites, but treatments varied from site to site depending on opportunities for improvement. ICM treatments included changes in planting density or application of manure or lime. Varieties grown always included a farmer-selected hybrid and, in some cases, open-pollinated varieties (OPV). Following are preliminary results of the first season experiments.

Fertilizer application in South Sulawesi, Indonesia.

Indonesia

Thirty on-farm trials were conducted in five key maize-producing provinces that account for 80% of Indonesia's maize production. Sites represent a wide range of climate, soils, cropping systems, and cropping practices. Hybrid maize was grown in all trials and ICM treatments varied depending on site. Across all sites, a highest average yield of 8.8 t/ha was achieved in NPK-ICM treatments, which was 19% or 1.4 t/ha higher than the yield achieved by farmers (**Figure 2**). The yield increase was related to both improved crop and nutrient management. Average yield at sites ranged from 7.2 t/ha in Central Java to 10.9 t/ha in East Java (**Table 1**). Highest yield in individual fields recorded at each site ranged from 9.4 t/ha in Lampung to 13.7 t/ha in Central Java, which was close to the genetically and climate determined yield potential simulated with the model Hybrid-Maize **>http://www.hybridmaize.unl.edu<**.

Table 1. Maize yield and yield response to fertilizer N, P, and K application in five farmers' fields at each experimental site, Indonesia, one season, 2004/05. Data are the average across treatments with and without improved crop management.

Site	Yield response, t/ha			Yield, t/ha	Highest yield, t/ha	Potential yield[1], t/ha
	+N	+P	+K	+NPK	+NPK	
North Sumatra	2.5	1.5	0.8	10.8	11.6	-
Lampung	2.4	0.6	1.1	7.6	9.4	10.1
Central Java	4.7	1.6	0.7	7.2	13.7	12.0
East Java	4.0	0.5	0.8	10.9	12.8	13.9
South Sulawesi	1.9	1.7	1.1	7.8	9.6	-
All sites	3.1	1.2	0.9	8.7	11.4	12.0

[1] Based on Hybrid-Maize model simulation

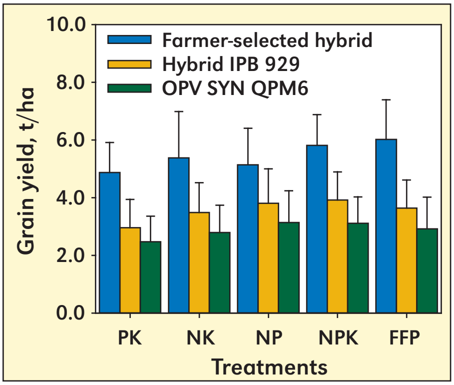


Figure 3. Grain yield of selected maize varieties in three farmers' fields, Isabela, Philippines, 2005. Data are the average across planting density.

The Philippines

One of the three project sites in the Philippines is located in the province of Isabela, which has 200,000 ha of land under maize and contributes 25% of the total production in the country. Five on-farm trials were conducted at this site during the 2005 wet season (May to October). Three varieties (farmer-selected hybrid, hybrid IPB 929, and OPV SYN QPM6) were planted at two densities of 83,000 plants/ha as commonly practiced by farmers and 67,000 plants/ha as suggested by researchers. Only data from three sites could be harvested because of severe drought in two farms. Yields were close to 6 t/ha in NPK treatments and the highest yield recorded in a single farm was 8.2 t/ha.

There was no significant difference in yield among NPK and FFP treatments. The average plant population at harvest was 27 to 29% lower than at seeding because of severe rainfall during emergence and drought problems during the growing season. Real-time nutrient management strategies are needed at sites with such variation in environmental conditions to adjust fertilizer rates to season-specific conditions. The yield response to fertilizer N, P, or K application was generally small, particularly for N because yield was largely limited by environmental constraints. Larger yield responses to fertilizer application can be expected in years with more favorable weather conditions. There were, however, large differences in yield among varieties (**Figure 3**).

Farmer applying water and fertilizer to maize in the Red River Delta, North Vietnam.

Vietnam

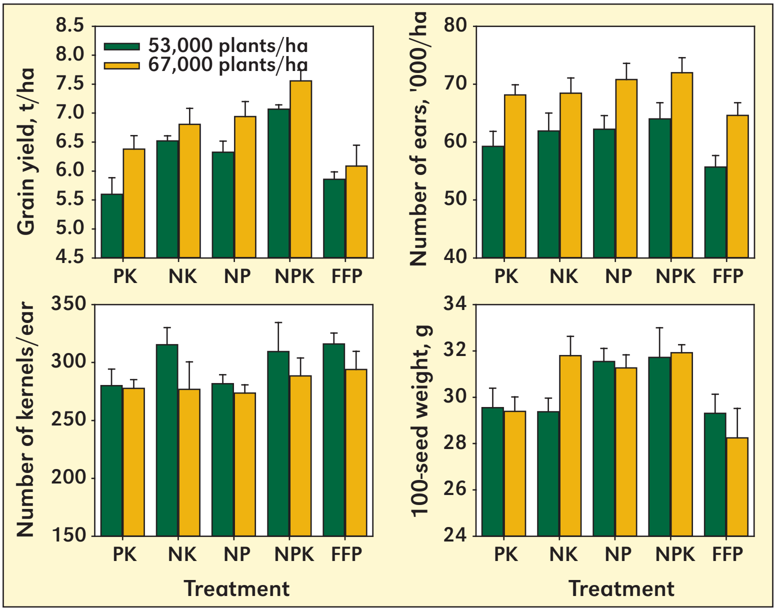
Project sites in Vietnam are located in four major agro-ecological zones representing key areas of corn production (Red River Delta, Central Highlands, Southeastern Vietnam, and the Mekong Delta). The selected provinces account for 65% of Vietnam's total maize production. In 2005, the first 25 on-farm trials were established in three provinces in North, Central, and Southeastern Vietnam. Hybrid varieties were grown at two planting densities that followed farmers' practice and a researchers' recommendation. Average yield in the first season ranged from 6.5 to 7.9 t/ha (**Table 2**).

Nutrient limitations followed the order N>P>K with moderate, average yield responses of 0.9, 0.7, and 0.6 t/ha to fertilizer N, P, and K application, respectively. Fertilizer rates applied by farmers averaged 107 kg N, 30 kg P_2O_5, and 63 kg K_2O/ha. Fertilizer

Table 2. Maize yield and yield response to fertilizer N, P, and K application in five farmers' fields at each experimental site, Vietnam, one season, 2005. Data are the average across two planting density treatments.

	Yield response, t/ha			Yield, t/ha	Highest yield, t/ha
Site	+N	+P	+K	+NPK	+NPK
Sonla	1.1	1.1	0.9	6.6	7.4
Daklak (*Rhodic Ferrasol*)	0.6	0.4	0.3	6.5	8.3
Daklak (*Lithic Luvisol*)	0.9	0.6	0.4	7.9	8.5
Dong Nai (*Luvisol*)	1.3	0.7	0.7	7.3	8.1
Dong Nai (*Ferrasol*)	0.6	0.6	0.5	7.5	8.6
All sites	0.9	0.7	0.6	7.2	8.2

Figure 4. Yield and components of yield in five farmers' fields in Dong Nai Province (Luvisol), Southeastern Vietnam, 2005.



rates in NPK treatments were 180-200 kg N, 90-120 kg P_2O_5, and 120-150 kg K_2O/ha following typical rates applied in fertilizer experiments with maize in Vietnam to exclude nutrient limitations and estimate nutrient-limited yield gaps. The latter will be used to calculate site-specific fertilizer recommendations based on data from two crops.There was a clear trend of increased yield at higher planting densities in all treatments as shown in the example of Long Khanh District in Dong Nai Province (**Figure 4**).

Preliminary results of on-farm trials with maize in Indonesia, the Philippines, and Vietnam clearly indicate sufficiently large yield gaps and significant opportunities to increase yield and profitability, if crop and nutrient management are fine-tuned to site-specific conditions. Farmers will probably need to adjust both timing and amount of fertilizer N, P, and K, and use split applications to better match crop demand for nutrients. Nutrient limitations often became more obvious once other constraints to yield were removed. Plant populations of 65,000 to 75,000 plants/ha are required to achieve high yields under favorable conditions in tropical Asia. In drought-prone areas, plant populations must be lower than that. BC

Dr. Witt is Director, PPI/PPIC-IPI Southeast Asia Program, Singapore, e-mail: cwitt@seap.sg. Mrs. Pasuquin is Agronomist, PPI/PPIC-IPI Southeast Asia Program, Singapore, e-mail: jpasuquin@seap.sg. Dr. Dobermann is Professor, University of Nebraska, Lincoln; e-mail: adobermann2@unl.edu.

Acknowledgements

The authors wish to thank the following for their invaluable contributions to this project. Indonesia: Mrs. Sari S. Girsang (AIAT North Sumatera), Mr. Andarias M. Murni (AIAT Lampung), Mr. Supadmo (AIAT Central Java), Mr. Suwono (AIAT East Java), Mr. P. Tandisau (AIAT South Sulawesi), Dr. S. Saenong (ICRI), Dr. Subandi (ICRI), Dr. D. Setyorini and Dr. F. Agus (ISRI), and Dr. S. Kartaatmadja (PPI/PPIC-IPI). Philippines: Dr. R. Labios (UPLB), Dr. A. Ocampo (IPB), Mr. H.C. Gines (PhilRice), Mr. C. Lapoot (NOMIARC); Mr. S. Tumamang (CVIARC). Vietnam: Dr. P.S. Tan (CLRRI), Dr. T. T. Son (NISF), Dr. D.T. Binh (IAS), Dr. Nguyen My Hoa, and Dr. Ngo Ngoc Hung (Cantho University); Dr. Ton Nu Tuan Nam (WASI). Funding for this project is provided by Canpotex International Pte. Ltd., International Fertilizer Industry Association (IFA), IPI, and PPI/PPIC.

The Three R's of the Fertilizer Industry

My grandmother was born in 1892. She grew up in an era of the one-room school house, where grades 1 through 6 were taught the three R's…the basics of 'Readin', 'Ritin', and 'Rithmetic.'

Such an education, simple as it was, provided a strong foundation and sustained the school children of her generation through productive and fulfilling lives.

Two generations later and the three R's have taken on new meanings. The environmental movement reminds us to reduce, reuse, and recycle and the fertilizer industry is reminding us — right rate, right time, and right place.

Right rate, right time, and right place are the foundation of efficient plant nutrient management. Applying plant nutrients at a rate required to produce a target yield and timed so that nutrients are available to the crop when it needs them and placed where roots can best access them are best management practices — BMPs for wise use of plant nutrients. At the Potash & Phosphate Institute, we have been long-time proponents of proper rate, proper time of application, and proper method of placement as necessary BMPs that will help ensure fertilizer nutrients are used efficiently and effectively.

The three R's of nutrient management — right rate, right time, and right place — are simple principles that will sustain our farms and our environment for generations to come.

Terry L. Roberts
President, PPI

BETTER CROPS
WITH PLANT FOOD

Potash & Phosphate Institute
Suite 110, 655 Engineering Drive
Norcross, Georgia 30092-2837

Periodicals Postage