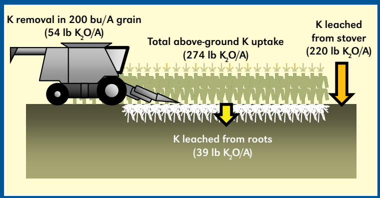
BETTER CROPS
WITH PLANT FOOD

A Publication of the International Plant Nutrition Institute (IPNI)
2010 Number 4

In This Issue...



Also:

...and much more

IPNI

www.ipni.net

BETTER CROPS WITH PLANT FOOD

Vol. XCIV (94) 2010, No. 4

Our cover: Dan Barker of Iowa State University gets a little help from son Quin while taking soil samples.
Photo by Bob Elbert

BETTER CROPS WITH PLANT FOOD (ISSN:0006-0089) is published quarterly by the International Plant Nutrition Institute (IPNI). Periodicals postage paid at Norcross, GA, and at additional mailing offices (USPS 012-713). Subscriptions free on request to qualified individuals; others $8.00 per year or $2.00 per issue. Address changes may be e-mailed to: cmees@ipni.net

POSTMASTER: Send address changes to *Better Crops with Plant Food*, 3500 Parkway Lane, Suite 550, Norcross, GA 30092-2844. Phone (770) 447-0335; fax (770) 448-0439. Website: www.ipni.net.

Better Crops with Plant Food is registered in Canada Post.
Publications mail agreement No. 40035026
Return undeliverable Canadian addresses to:
PO Box 2600
Mississauga ON L4T 0A9 Canada

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

CONTENTS

Note to Readers: Articles which appear in this issue of *Better Crops with Plant Food* (and previous issues) can be found as PDF files at the IPNI website: >**www.ipni.net/bettercrops**<

2010 Scholar Award Recipients Announced by IPNI

The 2010 winners of the Scholar Award sponsored by the International Plant Nutrition Institute (IPNI) have been selected. The awards of USD 2,000 (two thousand dollars) are available to graduate students in sciences relevant to plant nutrition and management of crop nutrients.

"We had a higher number of applicants for the Scholar Awards this year, and from a wider array of universities and fields of study," said Dr. Terry L. Roberts, IPNI President. "And the qualifications of the students are impressive. The academic institutions these young people represent and their advisers and professors can be proud of their accomplishments. The selection committee adheres to rigorous guidelines in considering important aspects of each applicant's academic achievements."

In total, 16 (sixteen) graduate students were named to receive the IPNI Scholar Award in 2010, with the most widespread geographic distribution ever for the awards. They are listed below by region and university/institution.

Africa: Mary Njeri Kibuku, Moi University, Eldoret, Kenya

Australia/New Zealand: Richard Flavel, University of New England, Armidale, New South Wales
Shu-Kee Lam, University of Melbourne, Horsham, Victoria

China: Qiong Yi, Chinese Academy of Agricultural Sciences, Beijing, China

Eastern Europe and Central Asia: Saken Suleimenov, Novosibirsk State Agrarian University, Novosibirsk, Russia

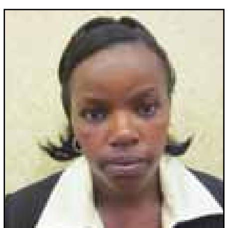
Latin America: Felipe Carmona, Federal University of Rio Grande do Sul, Porto Alegre, Brazil
Isabeli Pereira Bruno, São Paulo State University, Piracicaba, Brazil

North America: Ignacio Ciampitti, Purdue University, West Lafayette, Indiana, USA
Dylan Wann, University of Georgia, Tifton, Georgia, USA
Ronald F. Gonzalez, University of Florida, Gainesville, Florida, USA
Jared Barnes, North Carolina State University, Raleigh, North Carolina, USA

South Asia: Hafeez ur Rehman, University of Agriculture, Faisalabad, Pakistan
Neenu S., Kerala Agricultural University, Thiruvananthapuram, Kerala, India
Tanumoy Bera, University of Agriculture and Technology, Indian Agricultural Research Institute, New Delhi

Southeast Asia: Ngai Paing Tan, Universiti Putra Malaysia
Suphasit Sitthaphanit, Khon Kaen University, Thailand

Funding for the Scholar Award program is provided through support of IPNI member companies, primary producers of nitrogen, phosphate, potash, and other fertilizers. Graduate students attending a degree-granting institution located in any country with an IPNI program region are eligible. Following is a brief summary for each of the winners.

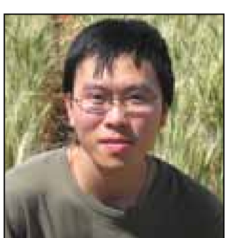


Mary Njeri Kibuku

Ms. Mary Njeri Kibuku is working toward a Ph.D. degree at Moi University in Kenya. Her dissertation is titled "Contribution of *Desmodium* spp. to Soil Fertility Rehabilitation in 'Push-Pull' Intercropping", which seeks to increase understanding of an integrated approach to balance N and P while reducing pest and disease infestation in maize production in western Kenya. The concept involves intercropping maize with stem borer moth-repellent plants such as *Desmodium* spp. (push), while an attractant host plant such as Napiergrass (pull) is planted around the intercrop. For the future, Ms. Kibuku hopes to continue research work, but also do teaching and perhaps even establish a facility with field demonstrations to allow more access to appropriate and beneficial technologies.

Richard Flavel

Mr. Richard Flavel started his Ph.D. program in 2010 at The University of New England in Armidale, New South Wales, Australia. His dissertation title is "Root Vigor of Cereal Genotypes in Response to Phosphorus Nutrition and Water Availability." The project brings together leading groups in Australia working on root architecture and new technologies to measure their functions for water and nutrient uptake in soils. The principles learned could be applied to better crop breeding and management for continued food security. For the future, Mr. Flavel intends to be involved with research that has practical implications for real world agricultural production systems, and also hopes to continue some teaching responsibility.



Shu-Kee Lam

Mr. Shu-Kee Lam is pursuing a Ph.D. degree at The University of Melbourne at Horsham, Victoria, Australia. His dissertation title is "Effect of Elevated Carbon Dioxide on Soil Nitrogen Dynamics in Rain-Fed Cropping Systems in Australia and China." A native of Hong Kong, he earned his Masters in 2005 and Bachelors degree in 2002 at The Chinese University of Hong Kong. Mr. Lam's research is investigating the effects of elevated atmospheric carbon dioxide on soil processes in a dryland grain production system at the free-air carbon dioxide enrichment (FACE) facility at Horsham. In 2009, he also carried out another series of experiments in Beijing, China, pertinent to crop response to climate change. For the future, his goal is to develop international expertise in plant adaptation and production in the context of climate change.

(continued on next page)

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium.

Qiong Yi

Ms. Qiong Yi is working toward her Masters degree at the Chinese Academy of Agricultural Sciences in Beijing. Her thesis is titled "Synchronizing Regulatory Mechanisms of Nitrogen Supply and Demand in Rice-Wheat Rotation System in Jianghan Plain." A native of Hunan, Ms. Yi graduated from Hunan Agricultural University in 2004. Objectives of her studies include defining suitable N rates for the rice-wheat system and determining the critical growth stages to guide in-season N recommendations. For the future, she intends for her career achievements to contribute toward sustainable agricultural development and environmental protection.

Saken Suleimenov

Mr. Saken Suleimenov has recently completed his Ph.D. at Novosibirsk State Agrarian University in Russia and is now at S. Seifullin Kazakh Agro Technical University in Kazakhstan. The focus of his research has been on mobilization of soil N in western Siberia and northern Kazakhstan. He graduated S. Seifullin Kazakh Agro Technical University in 2004. Mr. Suleimenov has received numerous awards and has been active in many cultural and sports activities as well as academic endeavors. For the future, he plans to continue research related to plant nutrition and soil N in northern Kazakhstan, including no-till and minimum tillage systems. Better understanding of tillage effects and mobilization of nutrients in soils of the dry-steppe zone of Kazakhstan could optimize fertilizer use and water resource saving technologies.

Felipe Carmona

Mr. Felipe Carmona is pursuing his Ph.D. degree in Soil Science at the Federal University of Rio Grande do Sul (UFRGS) in Porto Alegre, Brazil. He is doing part of his doctorate program at the International Rice Research Institute (IRRI) in the Philippines. His research focus is on K fertilization management of salt-affected soils. Mapping of soil salinity and K content in the coastal plains of Rio Grande do Sul will allow rice farmers to identify soil with high exchangeable sodium percentage (ESP) and to better plan the management of K fertilizer. For the future, Mr. Carmona hopes his studies might enable systems for determining different fertilizer recommendations depending on rice variety, providing better utilization of fertilizers and reduced environmental impact.

Isabeli Pereira Bruno

Ms. Isabeli Pereira Bruno is completing requirements for her Ph.D. in Crop Science at Luiz de Queiroz College of Agriculture, University of São Paulo, in Piracicaba, Brazil. Her dissertation is titled "Efficiency and Evolution of the N Absorbed from Fertilizer by Fertigated Coffee Plants in the Brazilian Cerrado." As coffee cultivation has shifted to non-traditional areas of the country, management practices need to be re-evaluated. Many questions are being raised about the nutrient efficiency and environmental effects of split applications of N fertilizers through irrigation systems. This research will provide more scientific information in determining the best timing and rate guidelines for N application to the coffee crop. For the future, Ms. Bruno plans to continue work related to plant mineral nutrition and soil fertility.

Ignacio Ciampitti

Mr. Ignacio Ciampitti started his Ph.D. degree program at Purdue University in July 2009, with a major in Cropping Systems/Maize Nutrition and Physiology. The main focus of his research is the study of N use efficiency (NUE) under different hybrids, plant densities, and N rates in high-yielding maize (corn) production systems. A native of Argentina, Mr. Ciampitti received his Masters and Agronomic Engineer degrees at the University of Buenos Aires. He has an impressive resume of academic achievements, awards, publications, teaching, and work experience. In the future, he hopes to be in a faculty position at a leading university or work in a scientific role with an international research institution.

Dylan Wann

Mr. Dylan Wann is working toward his Masters degree at the University of Georgia in Tifton. His thesis title is "Cover Crop Decomposition and Nutrient Cycling in Conventional- and Strip-Tillage Peanut and Cotton", examining the potential of crimson clover, rye, and wheat cover crops. Cover crops are widely utilized on the highly-erodible soils of the southeastern U.S. and questions have been raised regarding their potential for catching and cycling plant nutrients back to subsequent crops. Mr. Wann's research will help growers improve overall nutrient management in their cropping systems and better utilize fertilizer inputs. He is also dedicated to building a knowledge base and experience that can be shared to benefit subsistence farmers. For the future, he hopes to earn a Ph.D. degree, work in agricultural development abroad, and eventually teach at the collegiate level.

Ronald F. Gonzalez

Mr. Ronald F. Gonzalez is pursuing his Ph.D. degree at the University of Florida, Gainesville. His research is focused on requirements and environmental impact of P fertilization for the warm-season turfgrasses St. Augustine and zoysia. He is seeking to determine the critical P concentration below which maximum growth will not be attained. A native of Costa Rica, Mr. Gonzalez earned his Masters degree in Soil Science at the University of Wisconsin-Madison in 1998 and graduated from EARTH University in 1990. His work now is looking at how turfgrass species differ in their mechanisms of acquiring P, rates of uptake from solution, and how these differences interact related to P leaching and fertilization management. For the future, Mr. Gonzalez hopes to be involved in research and teaching, and he envisions a tropical research center to encourage students at many levels.

Jared Barnes

Mr. Jared Barnes has completed the requirements for his Masters degree at North Carolina State University in Raleigh, with a major in Floriculture/Plant Nutrition. His thesis title is “Characterization of Nutrient Disorders in Floriculture Species”, and his research looked at nutrient disorders of 12 species important to floriculture. A native of Tennessee, Mr. Barnes graduated from University of Tennessee at Martin in 2004 and has been active in a wide range of programs and activities. His research results will provide growers with the means to identify potential nutrient disorders. Used with information he collected on critical tissue concentration values, growers can better manage plant nutrition. For the future, he plans to earn a Ph.D. degree and continue research and education programs.

Hafeez ur Rehman

Mr. Hafeez ur Rehman is completing requirements for his Ph.D. program in Agronomy at University of Agriculture, Faisalabad, Pakistan. His dissertation title is “Nitrogen and Zinc Dynamics under Different Rice Production Systems.” Mr. Rehman’s research project involved splitting of N and zinc (Zn) at different stages and forms under varying water regimes and their availability, uptake, and partitioning in aerobic and transplanted basmati rice. He hopes to continue research on plant nutrition, particularly characterization of processes for enhanced Zn uptake and its further loading into rice grains to feed the malnourished people of the world. His work can also help farmers boost rice yields by improved water and nutrient management.

Neenu S.

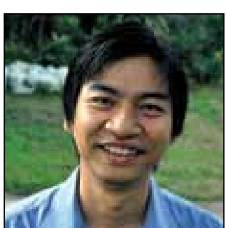
Ms. Neenu S. is pursuing her Ph.D. degree in Soil Science and Agricultural Chemistry at Kerala Agricultural University in India. Her dissertation title is “Site-Specific Nutrient Management for Bitter Gourd (*Momordica charantia* L.).” Intensive cultivation in Kerala, in addition to the tropical monsoon climate and undulating topography, have led to severe soil nutrient depletion. Field-specific, integrated crop management strategies are needed for optimum profitability. For the future, Ms. Neenu S. hopes to do research in the field of soil fertility to improve crop production, reduce poverty, and reduce potential harm to the environment resulting from unscientific use of fertilizers.

Tanumoy Bera

Mr. Tanumoy Bera is working toward his Doctorate degree in Soil Science at the Indian Agricultural Research Institute. His dissertation title is “Preparation, Characterization, and Evaluation of Biochar for Enhancing Nutrient Use Efficiency by Rice and Maize.” His research focuses on how to enhance nutrient use efficiency by applying biochar (a pyrolysis product of biomass). The study includes characterizing biochar from various plant-based residues produced by pyrolysis at different temperatures, optimizing rates of application, and assessing impact of biochar on soil properties after crop harvest. For the future, Mr. Bera hopes to continue research to solve practical problems faced by farmers.

Ngai Paing Tan

Mr. Ngai Paing Tan is working towards a Masters degree in the Department of Land Management at Universiti Putra Malaysia. His research program is titled “Evaluating Phosphorus Uptake of Oil Palm Genotypes and the High Affinity Phosphate Transporters Involved”. His study, involving P^{32} radioisotope, has shown large differences in phosphate upake among oil palm genotypes. A range of 12 to 46% of the available P applied to soil was taken up by various genotypes in a 9-month period. One benefit is that plants with better P uptake will have improved overall performance, optimizing yield and growth while minimizing the loss of applied P, especially in the highly weathered, acidic and impoverished soils in the tropics. For the future, Mr. Tan hopes to become a university research scientist and teacher, with emphasis on matching crop varieties to soils.



Suphasit Sitthaphanit

Mr. Suphasit Sitthaphanit is completing requirements for his Doctoral degree in Agronomy at Khon Kaen Univeristy in Thailand. His dissertation title is “Fertilizer Management for Maize in High-Leaching Sandy Soil”, and his research focus is on improving nutrient use efficiency on these soils under high rainfall conditions. Mr. Sitthaphanit notes that three or four split applications of NPK fertilizer and delaying basal applications until 7 to 15 days after emergence have proven to be effective. He states that his research offers an example of learning more about fertilizer best management practices and the concept of applying the right fertilizer source, at the right rate, the right time, and in the right place.

The IPNI Scholar Award recipients are selected by regional committees of IPNI scientific staff. The awards are presented directly to the students at their universities and no specific duties are required of them. Graduate students in the disciplines of soil and plant sciences including agronomy, horticulture, ecology, soil fertility, soil chemistry, crop physiology, and other areas related to plant nutrition are encouraged to apply. More information is available from IPNI staff, from individual universities, or from the IPNI website: >www.ipni.net/awards<. BC

The Fertility of North American Soils, 2010

By Paul E. Fixen, Tom W. Bruulsema, Tom L. Jensen, Robert Mikkelsen, T. Scott Murrell, Steve B. Phillips, Quentin Rund, and W. Mike Stewart

With the assistance of numerous private and public soil testing laboratories, the International Plant Nutrition Institute (IPNI) periodically summarizes soil test levels in North America (NA). Soil tests indicate the relative capacity of soil to provide nutrients to plants. Therefore, this summary can be viewed as an indicator of the nutrient supplying capacity or fertility of soils in NA. This is the tenth summary completed by IPNI or its predecessor, the Potash & Phosphate Institute (PPI), with the first summary dating back to the late 1960s (Nelson, 1980).

Photo by Bob Elbert

The 2010 summary includes results of tests performed by 60 private and public laboratories on approximately 4.4 million soil samples collected in the fall of 2009 and spring of 2010. Great appreciation is extended to all the labs cooperating. Their assistance has resulted in the largest summary of soil samples ever conducted in the U.S. and Canada.

Though IPNI attempts to be comprehensive and consistent in conducting the summary and avoid distorting the contributed data in any way, weaknesses exist in the summary process due to the diversity and dynamic nature of soil testing services:

- Quantity of contributed sample results is low in several states and provinces.
- An inexact time frame was given to labs. They were asked to contribute samples collected for decision making for the 2010 crop year, but the exact dates used in queries were left to individual interpretation.
- Not all sample results could be definitively associated with a particular state.
- It is likely that the better managers regularly test their soil and that their results may not be representative of those that do not soil test.
- Due to the requirement of nutrient management plans for many livestock operations, the percent of samples in the summary from manured fields could be higher than in the past for some regions and inflate soil test levels, especially for P. Summary protocol included separation of samples into manured and non-manured fields, but these categorizations were left to individual laboratories to define and very few laboratories had those metadata.
- Although an attempt was made to define calibration equivalency for each of the soil test categories among the various testing procedures, it is likely that error was introduced in this process.
- Some laboratory data were submitted using categories other than those specified in the sampling protocol, and interpolation routines were created and used to translate between the two systems.

Use of the Summary and Critical Levels

Important to appropriate use of this report is recognition that nutrient management should occur on a site-specific basis where management objectives and the needs of individual fields, and in many cases areas within fields, are recognized. Therefore, a general soil test summary like this one cannot reflect the specific needs of individual farms. Its value lies in calling attention to broad nutrient needs, trends, and challenges and in motivating educational and action programs that are in turn relevant to growers and their advisers.

Interpretation of the data reported here requires appreciation of the agronomic meaning of soil test levels. Critical levels are useful for that purpose. In this report, a critical level is defined as the level where recommended nutrient rates generally drop to zero in sufficiency approaches or to a crop removal level in build – maintenance approaches. It is the soil test level below which nutrient inputs are required to meet soil fertility management objectives. These objectives vary among the states and provinces, with each representing considerations of short- and long-term profit, market and environmental risks, accuracy and precision in soil fertility assessments, as well as many other factors. Critical levels therefore vary from state to state as various aspects of management receive different levels of emphasis.

Critical Bray P1 equivalent levels for the soils and typical cropping systems of the Great Plains and western Corn Belt are usually assumed to be around 20 ppm and to increase to 25 or 50 ppm for the eastern U.S. Certain crops, such as potatoes on some soils, will require much higher soil P levels with research showing agronomic response in the 100 ppm range. Critical ammonium acetate K equivalent levels for the relatively high cation exchange capacity (CEC) soils of western and central NA, are generally in the 120 to 200 ppm range. Critical levels are usually lower in eastern NA, and on low CEC soils may drop to 60 ppm.

State and province specific critical levels are available on-line (http://info.ipni.net/soiltestsummary).

Sample Volume

Since the 2005 summary (PPI, 2005), it appears a substantial increase in use of soil testing has occurred, assuming that the summary continues to represent about 75% of the total samples collected. For example, the volume of samples in the 2010 summary from the Corn Belt region (12 states plus Ontario) is approximately 3 million, 50% higher than in the 2005 summary. This likely represents one of the highest growth rates in soil testing ever experienced in NA. Though the summary cannot show when the jump occurred during the last 5 years, it may have occurred during the last year or two out of concern over the impact of recent nutrient use decisions on soil fertility levels and market-driven interest in improving future decisions. Growth in zone and grid sampling contributed to the increased sample volume.

Soil P

The median P level (50% of samples are above and below this level) for NA for the 2010 crop was 25 ppm, a 6 ppm decline from 2005. Phosphorus levels vary markedly among states and provinces **(Figure 1)** with the northern Great Plains generally having the lowest P levels as has been the case in past

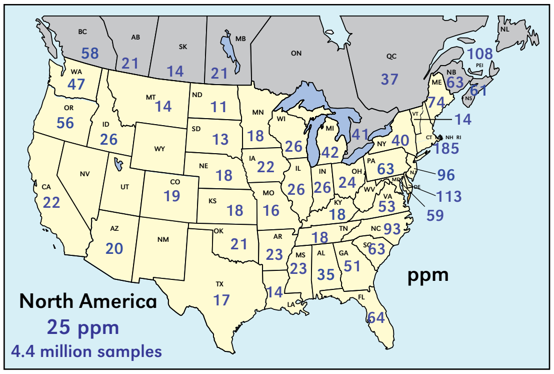


Figure 1. Median Bray P1 equivalent soil test levels in 2010 (for states and provinces with at least 2,000 P tests).

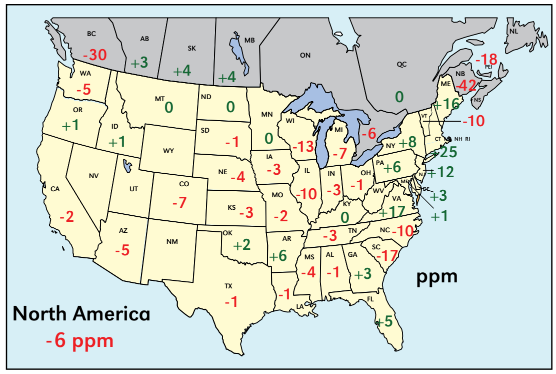


Figure 2. Change in median Bray P1 equivalent soil test levels from 2005 to 2010.

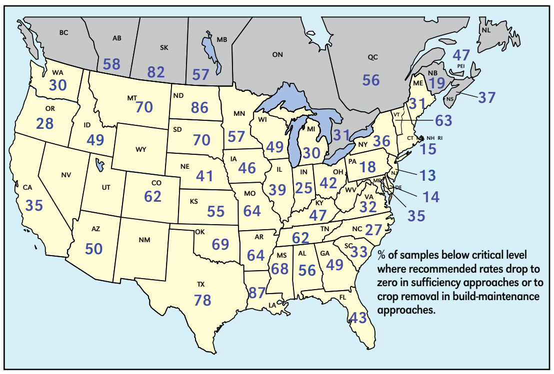


Figure 3. Percent of samples testing below critical levels for P for major crops in 2010.

summaries. However, unlike much of the rest of the intensively cropped regions of the country, this region tended to show increases in soil P or at least no declines from the 2005 summary **(Figure 2)**. Thus the regional differences now are not as large as in the past. The far eastern regions continue to have the highest soil P levels in NA, with some medians climbing higher in 2010.

The most consistent P declines since 2005 occurred across the Corn Belt and Central Great Plains. The median P level for the 12 major Corn Belt states plus Ontario declined from 28 ppm in 2005 to 22 in 2010. This decline has major agronomic significance since a high percentage of samples from this region now test below critical levels **(Figure 3)**. Considering that soil P levels are highly buffered, such large declines for a population of over 3 million samples over a 5-year period are surprising. The high sample volume and limited diversity in cropping systems of the Corn Belt offers opportunities for additional evaluation of aggregate data to gain insights into the cause of these declines.

A separate IPNI project that is evaluating partial nutrient balances in the U.S. (IPNI, 2010) was used to evaluate the relationship between P balance in the U.S. Corn Belt and changes in soil test P **(Figure 4)**. The resulting regression coefficient indicates that 62% of the variability in soil P changes could be explained by state P balance and the regression line passed very close to the origin where a balanced P budget equates to no change in soil P. This is evidence that much of the measured decline in soil P levels is due to the cumulative effects of crop removal exceeding P use across this region.

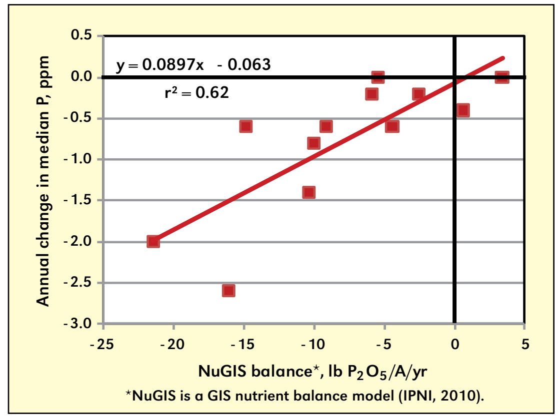


Figure 4. Annual change in median soil P level for 12 Corn Belt states as related to state P balance (fertilizer + recoverable manure – crop removal), 2005-2009.

Soil K

The median K level for NA for the 2010 crop was 150 ppm, a 4 ppm decline from 2005. Median K levels in many states east of the Mississippi River and in the provinces of eastern Canada are at or below agronomic critical levels, indicating that 50% or more of the sampled areas represented likely require annual K application to avoid yield losses **(Figures 5, 7)**. The higher K levels in the West

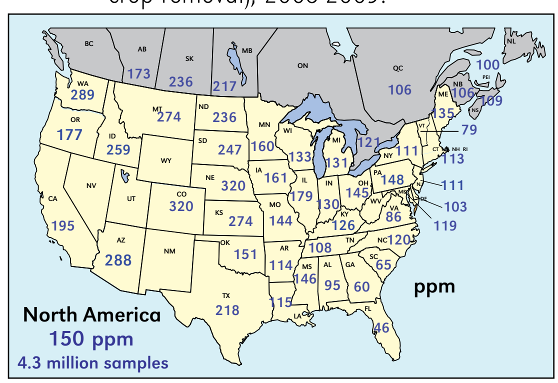


Figure 5. Median soil test K levels in 2010 (for states and provinces with at least 2,000 K tests).

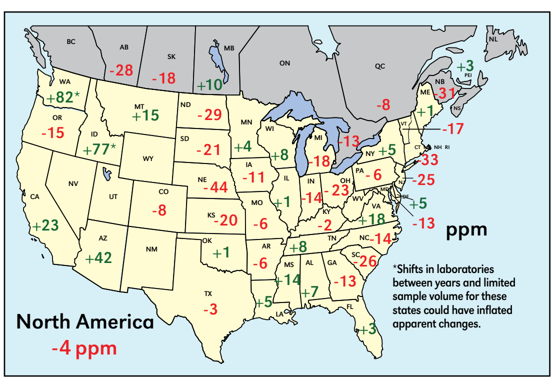


Figure 6. Change in median soil test K levels from 2005 to 2010.

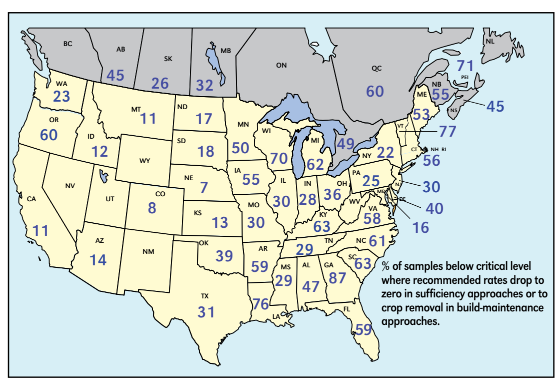


Figure 7. Percent of samples testing below critical levels for K for major crops in 2010.

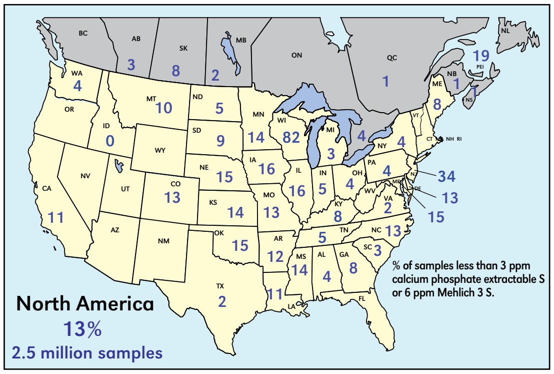


Figure 8. Percent of soils testing less than 3 ppm S in 2010 (for states and provinces with at least 2,000 S tests).

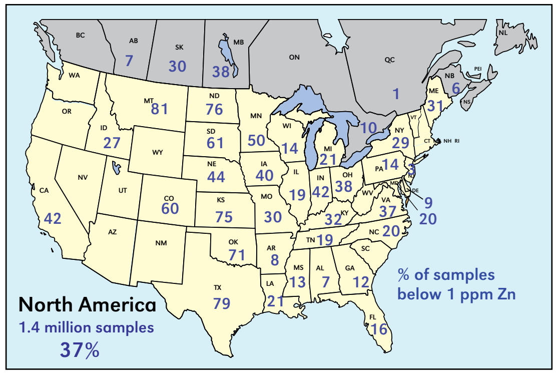


Figure 9. Soil samples testing less than 1.0 ppm DTPA equivalent Zn in 2010 (for states and provinces with at least 2,000 Zn tests).

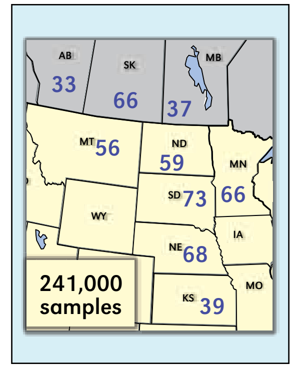


Figure 10. Percent of soils testing less than 4 ppm Cl-.

reflect the less weathered status of western soils. However, along the western Corn Belt and much of the Great Plains, crop removal far in excess of K additions (IPNI, 2010) are consistent with the declines in soil tests observed from 2005 to 2010 **(Figure 6)**. Many areas in the Northeast also experienced significant K declines.

In the Corn Belt, nutrient balance was not a good indicator of the observed changes in soil test K levels from 2005 to 2010, since it explained only 9% of the variability (data not shown). Though several shifts in K are larger numerically than the P changes, the agronomic significance of most of the Corn Belt K changes is considerably less than for P, especially when considering that the calibration scale for K is approximately 10 times that for P.

Sulfur, Zinc, and Chloride

Sulfur was analyzed on 2.5 million soil samples in the summary with 13% testing less than 3 ppm calcium phosphate equivalent S (6 ppm Mehlich 3 S) compared to only 4% testing below this level in 2005. This level of soil S should not be interpreted as a critical level, but just to help identify areas with the highest frequency of low levels. Some of the highest frequencies of low S occurred in the western Corn Belt and central Great Plains **(Figure 8)**, regions where reports of S deficiency in crops have been increasing.

Photo by Larry Reichenberger

Growth in zone and grid soil sampling has contributed to increased numbers of samples. Larry Hottman is shown collecting samples on his farm in Kansas.

This was the first Institute summary where the surveyed number of Zn soil tests was large enough to justify reporting. Of the 1.4 million Zn tests received, 37% were less than 1 ppm DTPA equivalent and 16% were less than 0.5 ppm. A critical level for this test is often considered to be near 1 ppm, but considerable variation exists among crops and soils. The summary indicates that many soils in NA should be responsive to Zn application, especially for Zn sensitive crops **(Figure 9)**. Of the total number of samples submitted to the survey, about one quarter contained Zn soil test information. This may have been due to either fewer customer requests for this analysis or fewer laboratories opting to report the results in the survey. However, Zn soil tests are often requested when insufficiency is suspected, so it may be that the survey results are biased toward lower levels.

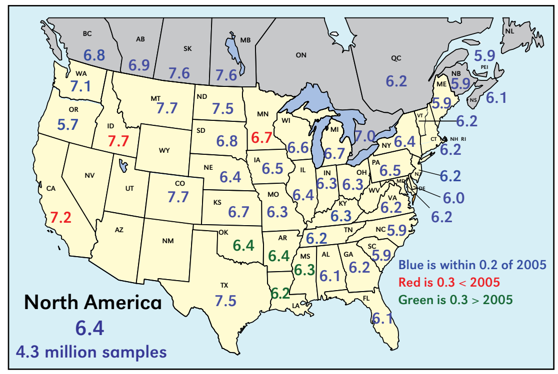


Figure 11. Median soil pH in 2010 and change from 2005 (for states and provinces with at least 2,000 pH tests).

Chloride levels are determined primarily on samples from the northern Great Plains where Cl- responsive crops are grown on low Cl- soils. These tests show a high frequency of low Cl- levels **(Figure 10)**.

Soil pH

The median pH for NA is 6.4, with 27% of the samples testing <6.0. A pH of 6.0 is highlighted because a pH above 6.0 is desirable for most cropping systems. Median pH is lowest in the southeastern U.S. and generally increases toward the west **(Figure 11)**. Median levels above but near 6.0 indicate that close to half of the surveyed population of tests in those states and provinces were acid enough that lime applications should be thoughtfully evaluated.

Dr. Fixen is IPNI Senior Vice President and Director of Research; e-mail: pfixen@ipni.net. Dr. Bruulsema is IPNI Northeast Region Director. Dr. Jensen is IPNI Northern Great Plains Region Director. Dr. Mikkelsen is IPNI Western Region Director. Dr. Murrell is IPNI Northcentral Region Director. Dr. Phillips is IPNI Southeast Region Director. Mr. Rund is with PAQ Interactive. Dr. Stewart is IPNI Southern and Central Great Plains Region Director.

References

International Plant Nutrition Institute (IPNI). 2010. A Preliminary Nutrient Use Information System (NuGIS) for the U.S. IPNI Publication No. 30-3270. Norcross, GA. Available on-line >www.ipni.net/nugis<.

Nelson, W.L. 1980. Better Crops 63(4): 6-10.

Potash & Phosphate Institute (PPI). 2005. Soil Test Levels in North America: Summary Update. PPI/PPIC/FAR Technical Bulletin 2005-1. Norcross, GA.

Role of Crop Nutrition in Narrowing the Yield Gap for Spring Wheat in Siberia

By G. Gamzikov and V. Nosov

Mineral fertilizers and other agro-inputs are important for achieving high and stable yields of spring wheat, the principle field crop in Siberia. This article reviews the attainable yield of spring wheat by the major soil-climatic zones through the region. The authors characterize the present status of fertilizer consumption in Siberia and, based on minimum nutrient requirements of crops, give a short-term estimate of fertilizer consumption in the region.

Siberia is located in the Asian part of Russia, occupying an area of about 10 million square kilometers (M km^2). Arable farming and animal husbandry are concentrated in the southern part of Siberia, with more than 56 M ha of agricultural lands. Siberia has about 23.5 M ha of arable land, representing about one-fifth of the total arable land area in Russia. Spring cereals such as wheat, barley, oats, and millet, as well as buckwheat, pulses, sunflower, potato, and vegetables are traditional crops in Siberia. Winter cereals include rye and triticale. Spring rapeseed, soybean, and sugar beet are promising crops giving high yields in this region. Cereals are grown on 70% of cropped area. Spring wheat dominates the cereal acreage (75 to 80%). However, the average grain yield of spring wheat in Siberia over the 5-year period of 2004 to 2008 was only about 1.3 t/ha.

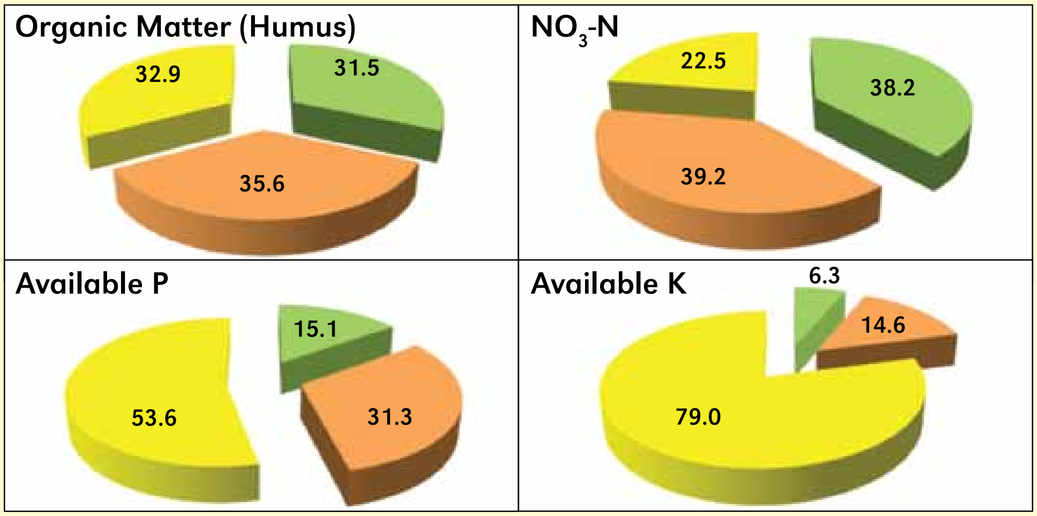
The grain belt of Siberia, comprising several soil-climatic zones, is characterized by diversity in annual rainfall (230 to 550 mm), the sum of active temperatures above 10 °C (1,400 to 2,800 growing degree days), and length of vegetation or frost-free period…100 to 140 days. In the forest zone, arable soils are represented by soddy-podzolic and grey forest soils occupying 17% of land in Siberia. Podzolized, leached, and common chernozems, and also meadow chernozem soils (63%) are spread throughout the forest-steppe zone. Southern chernozems and chestnut soils (14%) are dominant in the steppe zone. Soil fertility parameters affect crop production potential in the various soil zones of Siberia. A recent agrochemical soil survey indicated that organic matter (humus) content in Siberian soils can be very low to low (<4.0%), medium to high (4.1 to 8.0%), and high to very high (>8.1%), with about one-third of the monitored arable area under each group **(Figure 1)**. Acid arable soils, which need liming for optimal yield, occupy about 2 M ha in the region.

Nitrate-N (NO_3-N), is the major source of soil N for plant nutrition (Gamzikov, 1981). Siberian soils have a high potential to accumulate NO_3-N during the fallow season, after late summer tillage following perennial grasses, pulses, and annual grasses. Spring wheat grown after fallow and the above-mentioned crops has no requirement for additional application of N fertilizer. Two-thirds of the area sowed to field crops, following other preceding crops, has low soil N status and requires annual application of N fertilizer. According to routine soil analyses, slightly more than half of Siberian arable soils have high and very high content of available P, about one-third of soils test medium to high, and only 15% of soils are low to very low in available P **(Figure 1)**. The lowest content of P (low and very low classes) is observed in soddy-podzolic soils (57%), and in southern chernozems and chestnut soils (40%). Most soils (79%) have high to very high contents of available K **(Figure 1)**. Taking into consideration the status of soil nutrients in Siberian soils, annual recommendations for cultivated crops include N on 16 M ha, P fertilizer on more than 10 M ha, and K fertilizer on 5 M ha.

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; ppm = parts per million.

Spring wheat is grown on millions of hectares of land in Siberia, but yields in recent years have averaged only about 1.3 t/ha.

Soil-climatic conditions in three natural zones of Siberia are favorable for obtaining high yields of spring wheat when recommended crop management practices are followed **(Table 1)**. The role mineral fertilizers play in crop production is most important in the forest zone. Without plant protection and application of mineral fertilizer, spring wheat grain yields fail to exceed 1.0 t/ha. But intensive agro-technologies can produce 2.6 to 4.5 t/ha. Unstable rainfall, low soil NO_3-N, and low available P in some soil provinces limit yield formation on dark grey forest soils, podzolized, leached and common chernozems, and meadow chernozem soils in the forest-steppe zone. Here, the average grain yield for spring wheat does not exceed 1.5 t/ha under extensive systems of crop production, and only 2.0



		High and very high	Medium to high	Very low and low
Organic matter (Humus), %		≥ 8.1	4.1 – 8.0	≤ 4.0
NO_3-N, ppm (0-40 cm soil layer)		≥ 15.1	10.1 – 15.0	≤ 10.0
Available P, ppm P_2O_5	0.2 M HCl[1]	≥ 151	51 - 150	≤ 50
	0.5 M CH_3COOH[2]	≥ 151	51 - 150	≤ 50
	1% $(NH_4)_2CO_3$[3]	≥ 46	16 - 45	≤ 15
Available K, ppm K_2O	0.2 M HCl[1]	≥ 171	81 - 170	≤ 80
	0.5 M CH_3COOH[2]	≥ 121	41 - 120	≤ 40
	1% $(NH_4)_2CO_3$[3]	≥ 401	201 - 400	≤ 200

[1]soddy-podzolic soils [2]grey forest soils and noncarbonated chernozems [3]carbonated chernozems and chestnut soils

Figure 1. Distribution (%) of arable soils in Siberia in fertility classes according to status of soil organic matter, NO_3-N, and available P and K. (Source: Russian Res. Inst. of Agrochemistry, 2005.)

t/ha in years with especially favorable hydrothermal conditions. Attainable grain yields with recommended, intensive agro-technologies range between 2.2 and 4.0 t/ha. In the steppe zone (in view of the considerable moisture deficit in these southern chernozems and chestnut soils, and their low capacity to mobilize N), the average grain yield for spring wheat under an extensive system of crop production is usually under 1.0 t/ha. Nevertheless, it is possible to improve yield to 1.5 to 2.2 t/ha in this zone if all recommended agro-technologies are applied.

The application of mineral and organic fertilizers in combination with other agro-inputs and recommended agro-technologies allows growers to realize the existing yield potential in every soil-climatic zone while eliminating, or at least alleviating, the negative impact of common natural and anthropogenic factors. **Table 2** summarizes the average grain yield increase for spring wheat due to application of combinations of fertilizer nutrients in Siberia. The highest effect of fertilizers on grain yield can be observed on soddy-podzolic and grey forest soils – the agronomic efficiency of applied fertilizer nutrients is generally in a range of 4 to 9 kg high quality grain per kg of nutrients ($N+P_2O_5+K_2O$).

The appropriate tillage method in combination with the recommended use of fertilizers and other agro-inputs allows growers to better realize their yield potential **(Figure 2)**. Accumulated research data and growers' practice indicate that conservation tillage technologies coupled with recommended application of all agro-inputs, including mineral fertilizers, generates the highest grain yields (1.5 times higher), decreases the cost of grain production (by 17%), and thus increases profits (by 25%).

Despite this, mineral fertilizer use in Siberian agriculture has declined by more than 10 times over the last 20 years **(Table 3)**. Nutrient balance calculations for Siberia clearly indicate a negative balance for all three nutrients **(Table 4)**. In fact, total fertilizer inputs account for only 11% of crop nutrient removal in recent years. The short-term forecast (up to 2015) for increased mineral fertilizer consumption gives hope for a gradual alleviation of nutrient deficiencies and a considerable gain in spring wheat yields. Currently, Siberian agriculture has to rely on crop management

Table 1. Possible grain yields (t/ha) of spring wheat depending on soil-climatic conditions and systems of agriculture in Siberia (Gamzikov et al., 2008).

Natural zone	--- Climatic and soil limitations[1] ---			--- System of agriculture[5] ---		
	Solar radiation[2]	Rainfall[3]	Soil fertility[4]	Extensive	Ordinary	Intensive
Forest	4.0-5.8	3.8-5.0	0.6-1.5	0.5-1.0	0.7-1.6	2.6-4.5
Forest-steppe	5.0-7.2	1.7-4.0	1.2-2.4	0.8-1.5	1.0-1.8	2.2-4.0
Steppe	6.0-8.6	0.8-2.2	1.0-1.6	0.4-1.0	0.8-1.6	1.5-2.2
Distribution of agricultural enterprises, %				35-40	50-60	10-15

[1]Possible yields when climate and soil factors are not limiting.
[2]Possible yield range with application of fertilizer (and lime if required) plus optimal rainfall.
[3]Possible yield range with application of fertilizer (and lime if required).
[4]Possible yield range without fertilizer or lime.
[5]Extensive: without fertilizers and plant protection.
Ordinary: 10 to 20 kg/ha $N+P_2O_5+K_2O$ in seed row and plant protection in selected fields.
Intensive system: recommended crop management technologies; use of all agro-inputs.

Table 2. Long-term average effect of mineral fertilizer use on grain yield of spring wheat on Siberian soils (Gamzikov et al., 2008).

Soil	Yield without fertilizers, t/ha	---Yield increase with fertilizers[1], t/ha --- N	P	NP	NPK
Soddy-podzolic soil	1.06	0.46	0.32	0.57	0.79
Grey forest soil	1.57	0.41	0.30	0.60	0.67
Chernozem	1.68	0.33	0.22	0.49	0.52
Chestnut soil	1.14	0.16	0.18	0.31	0.31

[1]40 to 60 kg/ha each of N, P_2O_5, and/or K_2O.
These findings summarize all field research in Siberia.

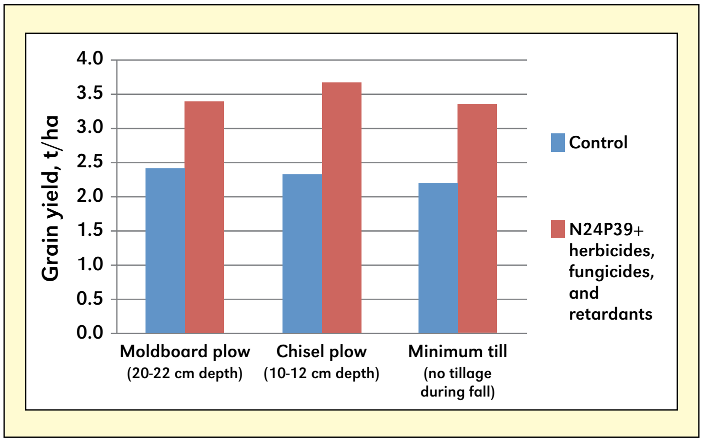


Figure 2. Effect of fall tillage method on grain yield of spring wheat grown after fallow in fallow-wheat-maize-wheat-barley crop rotation on leached chernozem; mean 1988-2000 (Kholmov and Yushkevich, 2006).

Available P and K content (0.5 M CH_3COOH) – 80 to 95 ppm P_2O_5 and 400 to 500 ppm K_2O. Fertilizer rates: 24 kg/ha N and 39 kg/ha P_2O_5.

systems that exploit indigenous soil fertility because of its limited use of mineral fertilizers and other inputs. Including fallow (the best predecessor for wheat in all natural zones of Siberia) in the rotation is the most commonly used practice. The fallow season in 3 to 4 year rotations allows for high accumulation of moisture reserves (160 to 220 mm within a 100 cm soil depth) and NO_3-N (100 to 120 kg/ha within a 40 cm soil depth). Fallow also decreases the number of weed seeds per square meter (to 30 to 35).

Specific soil-climatic conditions in Siberia (i.e., deep and prolonged soil freezing during the winter season, uneven distribution of rainfall through the vegetative period, and periodical droughts) increase the role of crop variety and its interaction with the crop management system. Spring wheat breeding in Siberia is done by 11 research institutions and agrarian universities. The State Register of Russia was expanded over the last 30 years (1977 to 2007) to include 63 new soft and 9 new durum varieties of spring wheat (Ruts and Kashevarov, 2008). It is noteworthy that Siberian varieties at present occupy 95% of the total area under spring wheat in the region. Breeding for higher yields of soft and durum spring wheat has progressed by 50% and 35%, respectively. Grain quality parameters have improved by 14 to 25% and 9 to 20%, respectively, during these last 30 years (Gamzikov, 1997; Ruts and Kashevarov, 2008). Modern spring wheat varieties have high yield potential (3.5 to 7.0 t/ha) and high grain quality (1,000 grain weight of 40 to 50 g, test weight of 780 to 820 g/l, protein content of 15 to 18%, gluten content of 32 to 40%). Most varieties registered for production over the last 8 years have complex immunity to pathogens and resistance to leaf rust, powdery mildew, and loose smut. Siberian research on the genetics of mineral nutrition of spring wheat has resulted in fundamentally new information about the genetic control of uptake and utilization of macronutrients and micronutrients in plants (Gamzikova, 2008). Specific genomes, chromosomes, genes, and cytoplasms controlling uptake and utilization of nutrients in wheat plants have been identified. Concepts and methodologies have been designed for breeding nutrient-efficient genotypes that are more adept at using soil and applied nutrients compared to modern varieties.

Table 3. Average annual fertilizer consumption ($N+P_2O_5+K_2O$) in Siberian agriculture, '000 ton.

Region	1986-1990	2001-2005	2006-2009	2015-2020 (outlook)
Western Siberia	832	53.7	70.9	260
Eastern Siberia	470	45.3	46.9	135
Siberia Total	1,302	99.0	117.8	395

Table 4. Average nutrient balance (kg/ha/year) in Siberian agriculture (2006-2009).

Nutrient	Crop removal	----- Fertilizer input ----- Mineral	Organic	Total	Balance	Input/ Removal, %
N	30.7	2.5	1.2	3.7	-27.0	12
P_2O_5	10.1	0.9	0.6	1.5	- 8.6	15
K_2O	24.4	0.3	1.7	2.0	-22.4	8
Total	65.2	3.7	3.5	7.2	-58.0	11

In the near-term, spring wheat will continue to be the dominant crop in Siberian agriculture. High and stable yields of spring wheat and also high grain quality in growers' fields will depend on adoption of best management practices recommended by researchers. This may be achieved with the corresponding development of grain export capabilities from Siberia and attractive grain prices at the grower's gate. BC

Prof. Dr. Gamzikov is Head, Laboratory of Actual Problems of Experimental Agrochemistry, Novosibirsk State Agrarian University; e-mail: gamolgen@rambler.ru. He is Academician of the Russian Academy of Agricultural Sciences. Dr. Nosov is Director, IPNI Southern and Eastern Russia Region, located in Moscow; e-mail: vnosov@ipni.net.

Dr. Gamzikov, left, and **Dr. Nosov**

References

Agrochemical characteristics of agricultural soils of Russian Federation. 2005. Russian Res. Inst. of Agrochemistry, Moscow. 183 p. (In Russian).

Gamzikov, G.P. 1981. Nitrogen in agriculture of Western Siberia. Nauka, Moscow. 268 p. (In Russian).

Gamzikov, G.P., I.F. Khramtsov, and V.K. Kalichkin. 2008. Proc. Annual Meeting of the Russian Academy of Agri. Sciences, Siberian Branch. Novosibirsk, pp. 58-78. (In Russian).

Kholmov, V.G. and L.V. Yushkevich. 2006. Intensification and resource conservation in agriculture of Western Siberia forest-steppe. Omsk State Agrarian University, Omsk. 396 p. (In Russian).

Ruts, R.I. and N.I. Kashevarov. 2008. Proc. Annual Meeting of the Russian Academy of Agri. Sciences, Siberian Branch. Novosibirsk, pp. 26-47. (In Russian).

Gamzikov, G.P. 1997. *In* Wheat: Prospects for Global Improvement (H.J. Braun et al., eds.). Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 55-59.

Gamzikova, O.I. 2008. Etudes on physiology, agrochemistry and genetics of plant mineral nutrition. Agros, Novosibirsk. 372 p. (In Russian).

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

By Reiles Zapata and José Espinosa

An article in this publication in 2007 reported on a successful, privately funded program in Peru which enables farm families to improve their standard of living and better manage land in coffee production. IPNI staff have assisted this program by providing agronomic education. Following is a recap of the story and an update on continued progress of the "Family Program".

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

Social and Environmental Effects

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

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

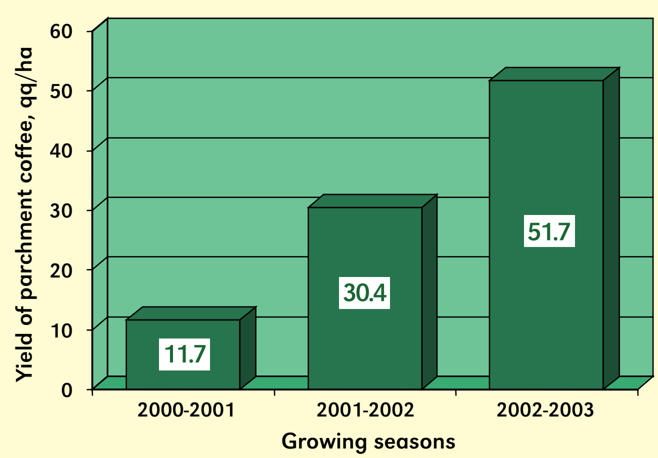
Agronomic and Social Assessment of Yield Recuperation

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

Effect of soil nutrition depletion on coffee growth and yield.

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

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



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

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

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

The experiment presented in **Figure 1** was designed to test the effect of this defined nutrient rate on coffee yield over a 3-year period. Knowing that the soils were depleted of nutrients, it was expected that the response would be evident in the second and third year. It was important to demonstrate a yield response to fertilizer application, but it was more important to demonstrate the yield potential after the plant stands regain the supporting biomass which is lost as a result of constant nutrient depletion. Timing and form of fertilizer application were also studied. IPNI was actively involved in the basic agronomic training of the technicians of the project and collaborated in the field research as advisor and provider of information.

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

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

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

The Family Program

Comercio & Cia decided to initiate an ample project with small farmers to achieve the proven possible yield increments. The need was evident for designing a project to help farmers

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

organize and legalize their land, to make credit for fertilizer available, to train farmers in the agronomic management of the crop, and to organize the chain of production so harvested coffee could be sold in a secure way and at a fair price.

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

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

The objective of the Family Program is to recuperate soil fertility to increase coffee production and to improve family income through balanced fertilization, best crop management practices, generation and efficient use of farm residues (leaves and trimmed branches, pulp from fruit processing and animal manures), rational use of natural resources (soil, water, forest), and reforestation. The Family Program officially initiated activities during the 2003-2004 coffee growing season with producers who summed a total area of 950 ha of land under coffee. The farmers did not commit all land under coffee to the program and requested credit to fertilize only part of the coffee fields. The program effectively covered a total of 450

Table 1. Evolution of average yields and prices paid to farmers involved in program.

Type	Average yield, qq/ha 2006	Average yield, qq/ha 2010	Average price, USD/qq 2006	Average price, USD/qq 2010	Average value, USD/ha 2006	Average value, USD/ha 2010
Family Program	30	40	80	120	2,400	4,800
Organic Program	10	12	87	128	870	1,536

ha. After all, this was a new project and much was heard about the allegedly negative effect of fertilizer use by many different organizations of the region. For this reason, the use of fertilizers by a small group of farmers generated much discussion and controversy. The opponents indicated, among other things, that the use of fertilizers would only degrade the soil more. Obviously, this did not happen and the families in the program enjoyed high coffee yields. Observing the benefits of the fertilizer and crop management on yield, the farmers committed all their coffee fields to the program and new requests to join the program were received. The program expanded rapidly and 7,500 ha of coffee production belonging to 2,500 households were committed for the 2005-2006 cycle. In the 2009-2010 cycle of production, 15,000 families were involved covering an area of approximately 12,500 hectares.

Benefits of the Family Program

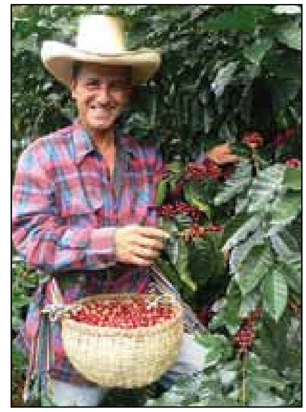
This private enterprise program evolved to comply with the social responsibility of the community that observed and supported the initiation and development of Comercio & Cia. The international coffee price has reached an acceptable level and this has made the program more valuable. Farmers now obtain excellent yields and receive good prices.

The outcome of the program after 7 years of working with small coffee producers has been very positive. The basic objectives of recuperating soil fertility to increase coffee yields and family income through organization, agronomic training and credit for fertilizer have exceeded expectations. The positive result has expanded to entire communities in the coffee growing areas of the Peruvian northeast. Families have increased coffee production, which has had important repercussions on productive and social investments. The tangible effects of the program are as follows.

Economic Benefits

Higher coffee production with better bean and cup quality has resulted in higher income, which improves the profitability of the program households and promotes savings and investment. The evolution of coffee yields and prices received by farmers is presented in **Table 1**.

Farmers participating in the program have recognized that there is little they can do to control international coffee prices. They also realize that the best approach to cope with fluctuating international coffee prices is through the production of higher coffee yield per unit area, making a more efficient use of external and internal inputs. They are convinced that a well managed farm stabilizes high yields, and this way they can enjoy the times of high international coffee prices, or protect their investment during periods of low coffee prices. High and stable yields have generated savings that make farmers less dependent on credit and less vulnerable to the fluctuating coffee prices or adverse changes in climate that could affect their plantations.



High, stable yields help protect farmers from fluctuating international coffee prices.

At the moment, many farmers have changed the layout of their coffee fields to make better use of the available land, and there is incentive to renovate old coffee plantations with new seedlings grown from select seeds. The use of these and other best management practices (BMPs) have promoted yields, which now range between 40 to 50 qq of parchment coffee per hectare per cycle.

The good outcomes from better crop and fertilizer management have encouraged farmers to invest in better infrastructure to process harvested berries. They have constructed better and bigger pools to ferment and wash their coffee berries, and have purchased equipment to remove the skin and pulp from seeds. Farmers have also invested in trays and solar covers to carefully dry the parchment coffee to ensure that the quality of the final product remains high.

Seedling production in a well-managed nursery provides homogenous planting material, which ensures high yields.

Many farmers have diversified farm production in the spaces liberated by the improved distribution of lands dedicated to coffee. Crops like corn, cassava, passion fruit, sugarcane, as well as livestock production and fish have been included in the normal operation of the farm. This generates food and extra income to the family, particularly at times during the year when coffee is not harvested.

Solar drying facilities preserve coffee bean quality.

The communities at the Coipa and Chirinos districts of the San Ignacio province and at the San José del Alto district of Jaén Province are the regions that have changed markedly after seven years of participating in the Family Program. At the moment, the landscape of the communities is greener with more canopy coverage, and coffee plantations are clean, orderly and show the effect of adopting basic technology. Surrounding villages and towns are more dynamic with new and diverse businesses supported by the higher income of farm owners and hired labor.

Diversification of farm activities ensures food diversity and income.

Social Benefits

As its name suggests, the main social benefit of the Family Program is the strengthening of the economic and unity of the family. This situation serves as a foundation for several other social benefits that derive directly from stable and solvent households. Notable examples include the implementation of basic sanitation by farmers participating in the program such as the construction of functional latrines, improvement of the local infrastructure, and the installation of electricity on these farms.

Greener and more orderly landscape is a product of basic technology adoption.

One of the most distressing signs of low and unstable yields was the lack of employment among communities in the region. Commonly, the main source of employment in the region ended once the coffee harvest season was complete. Both the landless population and farmers themselves were forced to look for jobs outside of their communities, generally in construction or services in distant cities. Alternatively, some were forced to move deeper into the forest to clear new lands and start again. Better yields require more hand labor, not only at harvest time but also during the complete season. Activities related to BMPs such as pruning, shade management, plantation renovation, fertilizer application, etc., need constant attention. Farmers also expend time in other implemented crops, or in animal care. All these profitable activities maintain farmers' self employed status and open stable job opportunities to the landless labor force.

Schooling is an important social benefit driven by better household income. Famers in the communities involved in the project have been able to keep their children in school to finish primary and secondary levels. Cultural levels of the families in the program keep improving, which has a decisive effect in the development of the community. Some farmers can send their children to continue their education at colleges in the city. However, most youngsters join the work force after finishing high school and take advantage of job opportunities that have resulted from the implementation of the program. Furthermore, they have the motivation to grow coffee on their own using the credit provided by the program. It is gratifying to see the attitude of this second generation of coffee farmers who eagerly embrace the new coffee technologies. This new generation is now leading the change and is instrumental in community organization, acting as coordinators for agronomic and credit training and in other roles.

Environmental Benefits

Finally, the environmental effect of the program is undisputed. The vigorous growth from coffee plants not only produces more fruit yield, but it also produces abundant biomass that is left in the field after trimming. Higher yields also result in larger amounts of pulp from the processing of fruit, which also comes back to the field after being composted. All of this additional recycling of nutrients increases soil organic matter and promotes the recuperation of soil fertility. The abundant cover from leaf litter and trimmed branches protects the soil against erosion. Nutrients applied to the soil also feed the surrounding trees that provide shade within coffee fields. Shade grows vigorously, creating good habitat, which in turn promotes biodiversity.

An important effect of the program is its ability to allow people to make a living on their existing farm area, which reduces the potential for deforestation of new sites to produce coffee. Actually, farmers satisfied with the good results in coffee production started to see reforestation as another long term economic and environmental investment. Thus, coffee producers are now reforesting areas of the farm not suitable for coffee or other crops (i.e., the perimeter of the farms, road sides and water ways). As time passes, farmers are spending more time in reforestation activities and progressively increasing their investment to the environment. The majority of the participating farms are located at the top of watersheds and reforestation at these particular sites will benefit the regional environment and contributes to the conservation of the main water sources of the region.

Awareness is also being raised among farmers about the need to treat the residual waters coming from the process of washing and de-pulping harvested coffee berries. Work is being conducted to find ways of using less water for processing purposes and to treat waste waters before disposing them in water bodies. Newly constructed washing pools also contribute by reducing water use in the washing process.

Reforestation on the perimeter of the farm is an economic and environmental investment.

Conclusion

After 7 years of implementation, the Family Program has demonstrated that a complete program of rural development can lead to effective crop management that increases coffee yields in socially marginal areas lacking governmental and private attention. The current good international coffee prices make production very profitable. However, if prices were to fall again due to shifting international conditions, the only way to attenuate the situation would be through efficient crop management that can maintain high yields. BC

Mr. Zapata is an economist and Coordinator of the Family Program, based in Jaén, Peru; e-mail: reileszr@molicom.com.pe. Dr. Espinosa is Director, IPNI Northern Latin America Program, located at Quito, Ecuador; e-mail: jespinosa@ipni.net.

Global Crop Intensification Lessens Greenhouse Gas Emissions

By Cliff Snyder, Tom Bruulsema, Valter Casarin, Fang Chen, Raúl Jaramillo, Tom Jensen, Robert Mikkelsen, Rob Norton, T. Satyanarayana, and Shihua Tu

The global population increased from 3.08 billion in 1961 to over 6.51 billion in 2005 (111% increase), and is expected to reach almost 9 billion by 2050. This growth of the human family will result in a 70% rise in food demand. Can such food production increases be met, and if so, what will the impacts be on greenhouse gas (GHG) emissions and climate change? A recently published scientific journal article (Burney et al., 2010) has provided some answers to these questions.

From 1961 to 2005, global crop production increased through the expansion of cropland area (*extensification*) and by increased yields on land already under cultivation (*intensification*). Land area in crop production grew from 960 to 1,208 million hectares (M ha), a 27% increase. Meanwhile, crop yields, weighted by production across crop groups, increased from 1.84 to 3.96 t/ha (135% increase). These yield improvements were made possible through farmer adoption of improved higher-yielding crop varieties and hybrids, increased fertilizer use, improved pest management, greater access to irrigation, increased soil conservation practices, and greater agricultural mechanization.

It has been estimated that agricultural production accounted for 10 to 12% of the total global GHG emissions in 2005. These emissions are comprised mainly of nitrous oxide (N_2O) and methane (CH_4), and sum to the equivalent of 5 to 6 gigatons (GT) of carbon dioxide equivalents (CO_2e). Approximately 60% of the global total N_2O emissions and 50% of the global CH_4 emissions have been attributed to agriculture (Flynn and Smith, 2010). Land use change, resulting from the clearing of forests and conversion of native lands for agricultural production, accounts for between 6 and 17% of the global total GHG emissions.

Our atmosphere experienced N_2O concentration increases from 270 parts per billion (ppb) from pre-industrial times to 319 ppb in 2005, or about a 0.26% per year increase (Davidson, 2009); and rises in carbon dioxide (CO_2) concentration from 318 parts per million (ppm) in 1961 to 380 ppm in 2005 (ftp://ftp.cmdl.noaa.gov/ccg/co2/trends/co2_annmean_mlo.txt), or about a 0.44% per year increase. These increases in GHG concentrations are increasingly thought to aggravate global warming and result in climate change issues.

The world's fertilizer N use was approximately 93 million metric tons (M t) in 2005. Using the Intergovernmental Panel on Climate Change (IPCC, 2006) Tier 1 N_2O emission factor of 1% (1 kg of N_2O-N emitted per 100 kg of N applied), this N use is estimated to cause the emission of 1.46 M t of N_2O or about 433 M t of CO_2e. Putting this in perspective, global fertilizer N consumption in 2005 may have accounted for 7.0 to 8.6% of the global GHG emissions in 2005 (Flynn and Smith, 2010).

Abbreviations and notes: N = nitrogen.

1 gigaton (Gt) = 10^9 tonnes = 10^{12} kg = 1,000 Tg
CO_2e = carbon dioxide equivalent in radiative forcing or global warming potential
CO_2e is 296 for N_2O and 23 for CH_4 (IPCC, 2006)

Investments in agronomic research have helped avoid GHG emissions.

Modern agricultural production relies heavily on fertilizer consumption. To help answer questions about the net GHG impacts, scientists at Stanford University in the U.S. (Burney et al., 2010) compared two alternative world (AW) scenarios with the real world (actual; RW) global GHG emissions from 1961 to 2005. In the AW1 scenario, cropland area is expanded, yields are constant as per 1961 levels, but the standard of living improves as in the RW scenario. The AW2 scenario also has cropland area expansion, but the standard of living is kept at the 1961 scenario level. Some of their assumptions and the estimated global GHG outcomes are shown in **Table 1**.

In the AW1 scenario, assuming fertilizer rates and crop yields constant at 1961 levels, much greater (> 7 times more) expansion of cropland area and encroachment upon natural areas was required to meet global food demands, compared to what actually happened in the real world. The AW2 scenario had similar assumptions, but also held per capita grain production (standard of living) constant. Nevertheless, AW2 still required a large expansion of cropland area (4.5 times more) to meet global food demands. In both the AW1 and AW2 scenarios, global CO_2e emissions increased markedly compared to the RW GHG outcome.

Although GHG emissions per hectare from crop production have increased, the net effect of intensification has been a large avoidance of emissions **(Table 1)**. At the same time, the increase in fertilizer production and consumption has made possible about 40 to 60% of the contemporary global crop and food production (Stewart et al., 2005; Erisman et al., 2008).

Expressing the benefits of intensive crop production a different way, 13.1 Gt of CO_2e emissions per year have been avoided, and each dollar invested in agricultural crop yields has resulted in 249 kg fewer CO_2e emissions, relative to technologies employed in 1961 (Burney et al., 2010).

Table 1. Comparison of real versus alternative world scenarios in meeting global food demands for 1961 to 2005, and their GHG emissions (prepared from data in Burney et al., 2010).

	Real World (RW)		Alternative World (AW1)	Alternative World (AW2)
	Crop production intensification		Crop production extensificiation	
	1961	2005		
Standard of living		Improved	Same as RW	Same as 1961
Crop yield, t/ha	1.84	3.96	1.84	1.84
Crop production, M t	1,776	4,784	4,784	3,811
Agricultural tractors, M	11.3	28.5	28.5[1]	23.7
Irrigated area, M ha	139	284	284[1]	298
Fertilizer (N-P_2O_5-K_2O) application rates, kg/ha	32	136	32	32
Global fertilizer consumed, M t	31	165	88	67
Cropland area expansion since 1961, M ha	–	248	1,761	1,111
Net increase in GHG emissions compared to RW, Gt CO_2e	–	–	590	317

[1] AW1 conservatively assumes machinery use and irrigation area remained the same as in the RW.

Important Implications

Two important points can be drawn from this study. First, investments in improving crop productivity are a cost-effective way to prevent increases in GHG emissions. Second, mitigation efforts must ensure that whole-system impacts of strategies to reduce GHG emissions be accounted for. While increasing efficiency of input use in crop production is a viable strategy, input reductions that limit yield increases are not.

Providing the needs of 9 billion people while protecting our planet and its landscape resilience may be the biggest challenge ever faced by humanity (Foley et al., 2005). To meet our food production needs while sustaining the planet and preserving significant parts of its natural ecosystems, ecologically intensive production systems (Cassman, 1999), improved nutrient use efficiency (Dobermann, 2007) through best management practices (BMPs), and better nutrient stewardship to achieve economic, environmental, and social goals have been advocated and advanced by members of the fertilizer industry and the agricultural community (Bruulsema et al., 2008; IFA, 2009; Snyder et al., 2009).

As a global society, are we ready to meet the challenges? BC

The authors are members of the Nutrients and Environment Work Group (WG02) of the International Plant Nutrition Institute (IPNI). All are staff members of IPNI, located in various regions of the world. Dr. Snyder is Chairman of the work group (e-mail: csnyder@ipni.net).

Acknowledgment

The authors thank Dr. Paul Fixen, IPNI Senior Vice President and Director of Research, for his input during preparation of this article.

Photo courtesy of Roger Elmore at Iowa State University

Increasing efficiency of input use is a viable strategy.

References

Bruulsema, T.W., C. Witt, F. García, S. Li, T.N. Rao, F. Chen, and S. Ivanova. 2008. Better Crops 92(2): 13-15.

Burney, J.A., S.J. Davis, and D.B. Lobell. 2010. Proc. Natl. Acad. Sci. 107(26):12052-12057.

Cassman, K.G. 1999. Proc. Natl. Acad. Sci. 96: 5952–5959.

Davidson, E.A. 2009. Nature Geoscience 2: 659-662.

Dobermann, A. 2007. Nutrient use efficiency – measurement and management. pp. 1-28. *In* Fertilizer Best Management Practices: General Principles, Strategy for their Adoption and Voluntary Initiatives vs Regulations. 259 pp. Proc. IFA International Workshop on Fertilizer Best Management Practices. 7-9 March 2007, Brussels, Belgium. International Fertilizer Industry Association, Paris, France.

Erisman, J.W., M.A. Sutton, J. Galloway, Z. Klimont, and W. Winiwarter. 2008. Nature Geoscience 1: 636-639.

Flynn, H.C. and P. Smith. 2010. Greenhouse gas budgets of crop production – current and likely future trends. 67 pp. International Fertilizer Industry Association. Paris, France.

Foley, J.A., R. DeFries, G.P. Asner, C. Barford, G. Bonan, S.R. Carpenter, F. S. Chapin, M.T. Coe, G.C. Daily, H.K. Gibbs, J.H. Helkowski, T. Holloway, E.A. Howard, C.J. Kucharik, C. Monfreda, J.A. Patz, I. C. Prentice, N. Ramankutty, and P.K. Snyder. 2005. Science 309: 570-574.

IFA. 2009. The Global "4R" Nutrient Stewardship Framework. Developing Fertilizer Best Management Practices for Delivering Economic, Social and Environmental Benefits. 10 pp. International Fertilizer Industry Association. Paris, France.

IPCC. 2006. Intergovernmental Panel on Climate Change Guidelines for National Greenhouse Gas Inventories. Volume 4: Agriculture, Forestry and Other Land Use. Chapter 11: N_2O Emissions from Managed Soils, and CO_2 Emissions from Lime and Urea Application. http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_11_Ch11_N2O&CO2.pdf (verified 30 July 2010).

Snyder, C.S., T.W. Bruulsema, T.L. Jensen, and P.E. Fixen. 2009. Agric. Ecosyst. Environ. 133: 247-266.

Stewart, W.M., D.W. Dibb, A.E. Johnston, and T.J. Smyth. 2005. Agron. J. 97:1-6.

Urea Volatilization Losses from Coffee Plantations

By Luis Leal, Alveiro Salamanca, and Siavosh Sadeghian

Responses to N are common in the coffee growing areas of the world. In Colombia, N recommendations vary from 120 to 300 kg N/ha/year, according to soil organic matter content, shade level, and plant density. Yield reductions of 30 to 50% are expected when N is not applied to the crop. Urea is the most common source of N used in coffee production in Colombia due to its high N content and relatively low price per unit. High N losses via volatilization from broadcast-applied urea are expected under the climate and soil conditions prevalent in the coffee production areas in Colombia. However, field research in the country to quantify the magnitude of these losses has been lacking.

A field study was conducted during 2005 to 2007 at two sites located at CENICAFE (Colombian Coffee Research Center) Experiment Stations. The sites are Naranjal and Paraguaicito, situated in the Departments (States) of Caldas and Quindío, respectively, in the heart of the Colombian coffee growing region. Climatic conditions of both sites are presented in **Table 1**. Soils are classified as Melanudands and Hapludands at Naranjal and Paraguaicito, respectively. Physical and chemical characteristics of both soils are presented in **Table 2**.

A coffee field in the peak of the production cycle (3 years of age) was chosen at each experiment station as a study site. Each field was planted with the Colombia coffee variety at 6,700 plants/ha managed at complete sunlight exposure. Ten blocks of two coffee plants were located inside each field. Each tree was an experimental unit. A PVC cylinder was placed 30 cm from the trunk to quantify NH_3 volatilization (observation unit). One experimental unit was fertilized superficially with 6.5 g of urea, while another corresponding unit did not receive urea and was considered the control or check treatment.

Each observation unit consisted of a static half-open collector made from a PVC cylinder that was 15 cm in diameter and 44 cm in height. Inside this cylinder, two laminar pieces of polyurethane (3 cm thick) were placed 15.4 cm apart from each other **(Figure 1)**. Each piece was soaked in 70 ml of a 0.5N sulfuric acid solution + 3% glycerin. The lower foam trapped the NH_3 liberated from the soil, while the upper lamina prevented the penetration of NH_3 from the atmosphere (Nömmik, 1973; Lara et al., 1999).

Ammonia volatilization was measured at days 1, 2, 3, 5, 9, 14, and 20 after urea application. The polyurethane laminas in every cylinder were replaced each day of evaluation and water was added in the same volume as the rain collected in adjacent containers. The bottom lamina was taken to the lab to determine the amount of NH_3 volatilized. Daily data of mean air temperature and rainfall was collected during the period of evaluation at two weather stations located near the evaluation sites.

Abbreviations and notes: N = nitrogen; NH_3 = ammonia; NH_4^+ = ammonium; CEC = cation exchange capacity.

Table 1. Climatic conditions prevalent at the two experimental sites (CENICAFE, 2005).

Site	Altitude, m	Temperature, °C	Relative humidity, %	Solar radiation, hr/year	Precipitation, mm/year
Naranjal	1,381	21.3	73.1	1,797	2,711
Paraguaicito	1,203	21.9	77.0	1,720	2,149

Table 2. Physical and chemical characteristics of the soils at the two experimental sites.

Site	Sand	Silt	Clay	Organic matter	pH	CEC
	----	----	%	----		$cmol^+/kg$
Naranjal	49	32	19	11.3	4.8	23
Paraguaicito	54	27	19	7.1	5.2	13

Table 3. Average values of N volatilization losses from coffee plantations at two evaluation sites in Colombia.

		Days after application						
		1	2	3	5	9	14	20
Site	Treatment	mg						
Naranjal	- urea	0.60	0.61	0.59	0.55	0.57	0.42	0.40
	+ urea	22.0	257.7	199.9	205.1	119.6	64.0	43.9
Paraguaicito	- urea	0.89	0.87	0.86	0.87	0.88	0.95	0.86
	+ urea	13.4	279.6	260.7	263.3	126.5	68.1	33.9

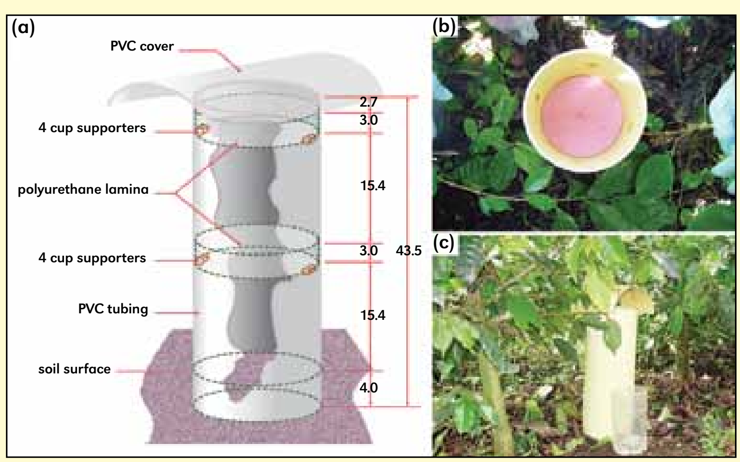


Figure 1. a) Diagram of the NH_3 collector. b) NH_3 collector with the lower polyurethane lamina installed. c) NH_3 collector in the field.

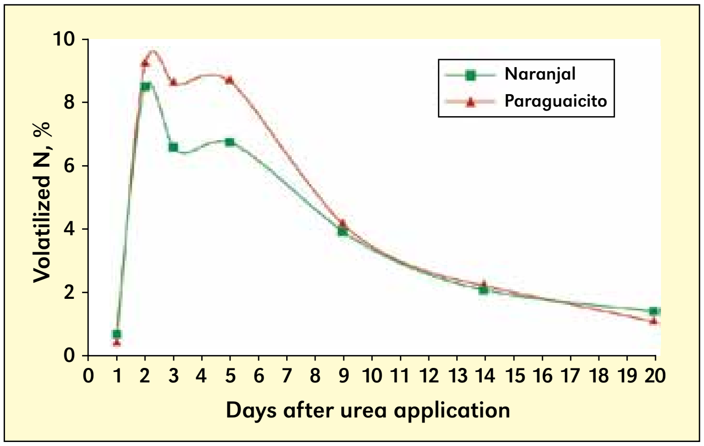


Figure 2. Average daily N losses at both evaluation sites.

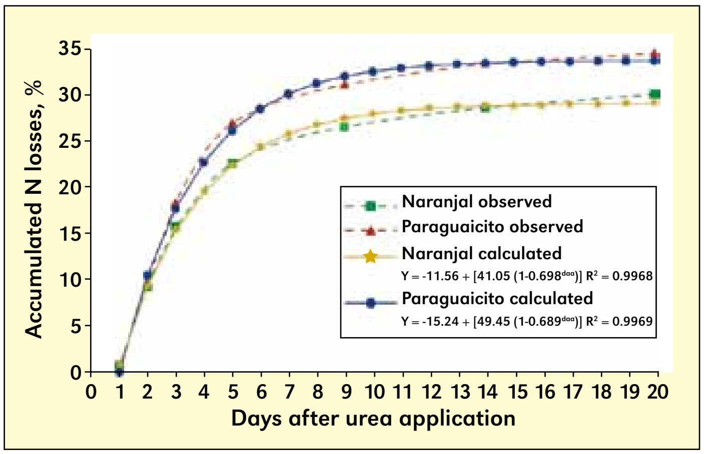


Figure 3. Accumulated observed and calculated N losses at both evaluation sites.

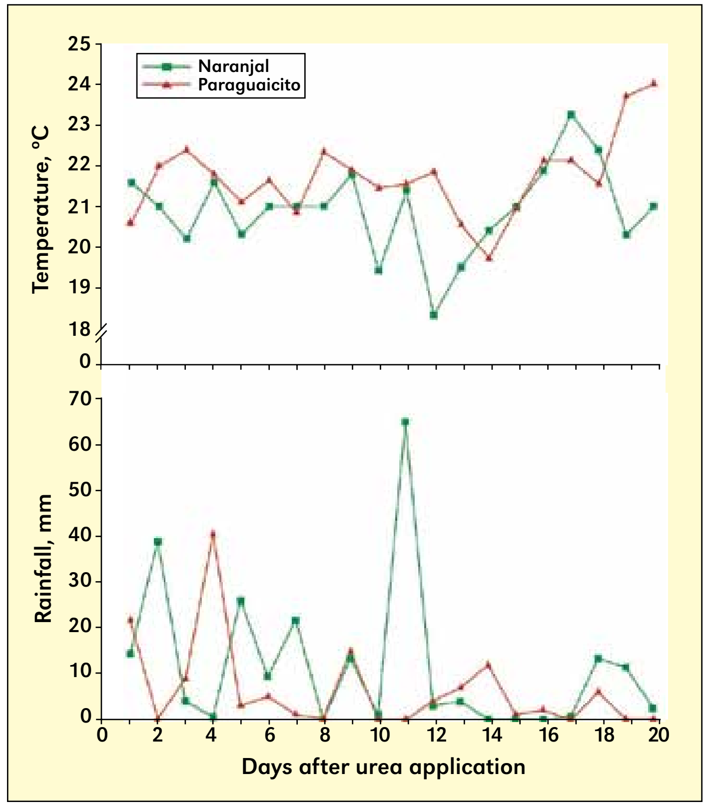


Figure 4. Mean daily air temperature and mean daily rainfall registered at the weather stations in Naranjal (March 14 to April 2, 2006) and Paraguaicito (April 27 to May 16, 2006) Experiment Stations.

Results and Discussion

The mean volatilization losses through time at both locations are presented in **Table 3**. At both sites, N losses from the surface applied urea treatment were significantly higher than the control without N application. The background N losses were very low and relatively constant through time. Background losses at Paraguaicito were higher (0.87 to 0.95 mg of N) than at Naranjal (0.40 to 0.61 mg of N). These background losses are in agreement with data reported in the literature for similar treatments (Barbieri and Echeverría, 2003; Sangoi et al., 2003) and probably are N forms liberated by regular microbial and plant activity.

The trend of N volatilization from the urea treatments was similar at both locations, with low losses the first day after application and a significant increase on the second day, moving from 22.0 to 257.7 mg of N at Naranjal and from 13.4 to 279.6 mg at Paraguaicito. Losses from the third to fifth day at Naranjal were slightly lower to those recorded on the second day, but were similar to those recorded on the second day at Paraguaicito. The amount of N volatilized decreased gradually at both sites from the fifth day until day 20 when the lowest N loss was registered.

The high N losses during the first days after urea application are a consequence of urea hydrolysis, which increases ambient pH around the granule, a condition that promotes NH_3 formation from the NH_4^+ formed during the initial reaction between urea and the soil surface (Kiehl, 1989; Vitti et al., 2002).

The daily losses, expressed as a percentage of the total N application, showed a similar volatilization trend at both sites **(Figure 2)**. Accumulated N losses are presented in **Figure 3**. Total N volatilization at the end of the evaluation period at Naranjal was 30% of the total N application, while 35% was volatilized at Paraguaicito. Ammonia volatilization during the first 5 days of evaluation was very high and reached 23% of the total N application at Naranjal and 27% at Paraguaicito. These N losses are similar to those reported for sugarcane plantations in Brazil (Costa et al., 2003).

Figure 3 also shows the accumulated data calculated with the best fitted regression model using the observed data at both sites. Observed and calculated data indicate that NH_3 losses reached a minimum at day 20. If the assumption is made that accumulated volatilization at day 20 represents 100% of the N losses, recorded data suggest that more than 95% is volatilized 10 days after urea application. This indicates that volatilization occurs in a short period of time and practices to minimize these losses need to be adjusted to this condition.

The difference in total loss between both sites could be associated with the soil and climatic characteristics of the experimental sites. Soil characteristics such as organic matter content, CEC, texture, and pH affect the magnitude of volatilization. Soils with higher CEC and higher organic matter content have a greater capacity to retain NH_4^+ released from the urea hydrolysis and this reduces volatilization (Fenn and Kissel, 1976; Fleisher et al., 1987). Data from this study suggest that differences in soil characteristics could be responsible for the differences in total volatilization losses since organic matter content and CEC were higher at Naranjal in comparison with the soil at Paraguaicito. However, the differences in soil pH and texture between the soils of both sites were likely not significant enough to explain the differences in the observed NH_3 volatilization.

It has been documented in coffee plantations in Colombia that air temperature in the top 2 m over the ground is highly correlated with temperature in the first 10 cm of the soil profile (Jaramillo, 2005). This condition is in turn influenced by other climate factors such as solar radiation, wind velocity, water evaporation, rainfall, and soil factors including tillage, organic matter content, and soil moisture. **Figure 4** shows the average temperature registered over the 20 days of evaluation at both sites. The data suggest that the lower average temperature at Naranjal during the evaluation period was associated with lower N volatilization losses. Volatilization losses are greater as temperature increases due to the increment in microbial activity, particularly microorganisms that produce the urease enzyme (Hargrove, 1988).

Figure 4 also shows daily precipitation through the evaluation period at both sites. At Naranjal, total accumulated precipitation during the 20 days of evaluation was 252 mm, while at Paraguaicito it was only 128 mm. The lower N volatilization at Naranjal can be related to the higher amount of rainfall during the first five days of evaluation, or the period when the highest amount of N losses occurred at both sites. Higher soil moisture due to more rainfall reduces N volatilization losses because it dilutes the concentration of OH^- ions that builds around the urea granule during urea hydrolysis and helps to incorporate NH_4^+ into the soil profile (Lara et al., 1997).

The combined plant density and age condition of the plantation could explain the fact that 40 mm of precipitation on day 2 at Naranjal did not move the urea far enough into the soil to shut down volatilization losses. Around 50% of the total amount of water which falls in a precipitation event is retained in the coffee plant canopy and in the thick mulch layer accumulated on the soil as a result of normal leaf loss and trimming (Jaramillo, 2003; Velásquez y Jaramillo, 2009). Consequently, only around 50% of the rainwater reached the soil to upset urea reactions at that point in time.

Conclusions

Data from this study demonstrate that NH_3 volatilization losses from urea applied to the soil surface in established coffee plantations are significant and occur over a short period of time. The combined effect of soil and climate influence the total N loss, but in any situation it is necessary to adjust fertilizer management practices to minimize these losses. BC

Acknowledgments

The authors acknowledge CENICAFE for its institutional support and to all CENICAFE technical staff who collaborated in this study.

Ing. Leal is Extensionist at the Colombian Federation of Coffee Growers (FEDECAFE). Ing. Salamanca is Research Assistant at Colombian Coffee Research Center (CENICAFE); e-mail: Alveiro.Salamanca@cafedecolombia.com. Ing. Sadeghian is Research Scientist at CENICAFE; e-mail: Siavosh.Sadeghian@cafedecolombia.com

References

Barbieri, P.A. y H.E. Echeverría. 2003. Revista de Investigaciones Agropecuarias 32:17-27.

Centro Nacional de Investigaciones de Café – Cenicafé. 2005. Archivo de información climática, Cenicafé, Disciplina de Agroclimatología. 552 p.

Costa, G., C. Vitti, H. Cantarella. 2003. Revista Brasileira de Ciência do Solo 27:631-637.

Fenn, L.B. and D.E. Kissel. 1976. Soil Science Society of America Journal 40:394-397.

Fleisher, Z., A. Kenig, I. Ravina, and J. Hagin. 1987. Plant and Soil 103:205-212.

Hargrove, W.L. 1988. *In* Bock. B. and D. Kissel (eds). Ammonia volatilization from urea fertilizers. Alabama, National Fertilizer Development Center, p. 17-37.

Jaramillo, A. 2005. Clima andino y café en Colombia. Chinchiná, Centro Nacional de Investigaciones de Café - Cenicafé. 192 p.

Jaramillo, R.A. 2003. Cenicafé 54(2): 134-144.

Kiehl, C.J. 1989. Revista Brasileira de Ciência do Solo 48:75-80.

Lara, A., G. Korndörfer, e A. Motta. 1997. Revista Brasileira de Ciência do Solo 21:481-487.

Lara, A., e P. Trivelin. 1990. Revista Brasileira de Ciencia do Solo 14:345-352.

Lara, A., P. Trivelin, J. Bendassolli, D. Santana, and G. Gascho. 1999. Communications in Soil Science and Plant Analysis 30:389-406.

Nömmik, H. 1973. Plant and Soil 39:309-318.

Sangoi, L., P. Ernani, V. Lech, G., and G. Rampazzo. 2003. Ciencia Rural 33:687-692.

Velasquez, S. and R.A. Jaramillo. 2009. Cenicafé 60(2): 148-160.

Vitti, G.C., J.E. Tavares Junior, P.H. Luz, J.L. Favarin, e M.C. Costa. 2002. Revista Brasileira de Ciência do Solo 26:663-671.

Statement of ownership, management, and circulation, (requester publications only). ***Better Crops with Plant Food*** **for No. 4, 2010. Printed from PS Form 3526-R**

Better Crops with Plant Food is published four times a year by International Plant Nutrition Institute (IPNI). Headquarter offices of the publisher are located at 3500 Parkway Lane, Suite 550, Norcross, Georgia 30092-2844. Publisher: IPNI, Norcross, Georgia 30092-2844. Editor: Donald L. Armstrong, IPNI, 3500 Parkway Lane, Suite 550, Norcross, Georgia 30092-2844. Owner is IPNI, Norcross, Georgia 30092-2844. Known bondholders, mortgagees, and other security holders owning or holding 1 percent or more of the total amount of bonds, mortgages, or other securities: None.

The purpose, function, and nonprofit status of this organization and the exempt status for federal income tax purposes has not changed during preceding 12 months. The average number of copies of each issue during the preceding twelve months is: a. Total Number of Copies Printed: 15,000. b. Paid and/or Requested Circulation: 1. Paid/Requested Outside-County Mail Subscriptions: 1,675. 2. Paid In-County Subscriptions: 0. 3. Sales through Dealers and Carriers, Street Vendors, Counter Sales, and Other or requested distribution outside USPS: 5,155. 4. Requested Copies Distributed by Other Mail Classes through the USPS: 400. c. Total Paid and/or Requested Circulation 7,230. d. Nonrequested distribution 1. Outside County Nonrequested Copies: 4,015. 2. In-County Nonrequested Copies: 0. 3. Nonrequested Copies Distributed through the USPS by Other Classes of Mail: 50. 4. Nonrequested Copies Distributed outside the Mail: 200. e. Total Nonrequested Distribution: 4,265. f. Total Distribution: 11,495. g. Copies Not Distributed: 3,505. h. Total: 15,000. I certify that this statement of ownership is correct and complete.

Agronomic Use of Phosphate Rock for Direct Application

By S.H. (Norman) Chien, Luis I. Prochnow, and Robert Mikkelsen

Phosphorus is critically needed to improve soil fertility and crop production in many areas of the world. Direct application of phosphate rock (PR) has been shown to be a valuable source of nutrients in some conditions. This article reviews the relative agronomic effectiveness of PR with respect to water-soluble phosphate fertilizer.

In many acid soils in the world, especially in the tropics, soil fertility limitations constrain successful crop production. These soils usually are low in plant-available P and often have a high P-fixing capacity that results in low efficiency of water-soluble P (WSP) fertilizers such as triple superphosphate (TSP) or diammonium phosphate (DAP) by crops. Application of unprocessed PR to soil can be an attractive alternative to WSP fertilizers in such cases.

Source of Phosphate Rock

The best predictor of the agronomic performance of PR is solubility, which is normally measured in the laboratory with neutral ammonium citrate (NAC), 2% citric acid (CA), or 2% formic acid. The solubility of PR reflects the chemical and mineralogical characteristics of the specific P minerals. The principal mineral in most PR sources is apatite, but it varies widely in physical, chemical, and crystallographic properties.

The chemical formula of apatite in some representative PR is shown in **Table 1**. In general, the NAC solubility increases as CO_3^{2-} substitution for PO_4^{3-} in the apatite structure increases. The solubility of PR is known to correlate well with crop response. **Figure 1** shows that crop response to finely ground PR depends on the source and the solubility.

The solubility of PR generally increases with smaller particle size. However, the agronomic effectiveness of ground and unground highly reactive PR sources does not strictly follow the solubility pattern. For example, the solubility of unground reactive PR (-35 mesh; 0.5 mm) is less than that of the same but ground PR (-100 mesh; 0.15 mm), but their agronomic effectiveness is similar under field conditions (Chien and Friesen, 1992) and greenhouse conditions. (See photos on next page). It is not sufficient to compare the solubility and the agronomic effectiveness of various PR sources based only on particle-size distribution. A solubility database of many PR sources around the world has been compiled by Smalberger et al. (2006).

Table 1. The solubility and empirical formula of apatites in some sedimentary phosphate rocks.

PR source	NAC[1], % P_2O_5 of rock	Empirical formula
North Carolina, USA	9.7	$Ca_{9.53}Na_{0.34}Mg_{0.13}(PO_4)_{4.77}(CO_3)_{1.23}F_{2.49}$
Gafsa, Tunisia	8.7	$Ca_{9.54}Na_{0.32}Mg_{0.12}(PO_4)_{4.84}(CO_3)_{1.16}F_{2.46}$
Bahia Inglesa, Chile	6.9	$Ca_{9.59}Na_{0.30}Mg_{0.12}(PO_4)_{4.90}(CO_3)_{1.10}F_{2.44}$
Central Florida, USA	5.3	$Ca_{9.74}Na_{0.19}Mg_{0.07}(PO_4)_{5.26}(CO_3)_{0.74}F_{2.30}$
Tennessee, USA	3.7	$Ca_{9.85}Na_{0.11}Mg_{0.04}(PO_4)_{5.54}(CO_3)_{0.46}F_{2.18}$
Patos de Minas, Brazil	2.5	$Ca_{9.96}Na_{0.03}Mg_{0.01}(PO_4)_{5.88}(CO_3)_{0.12}F_{2.05}$

[1]Neutral ammonium citrate (NAC)

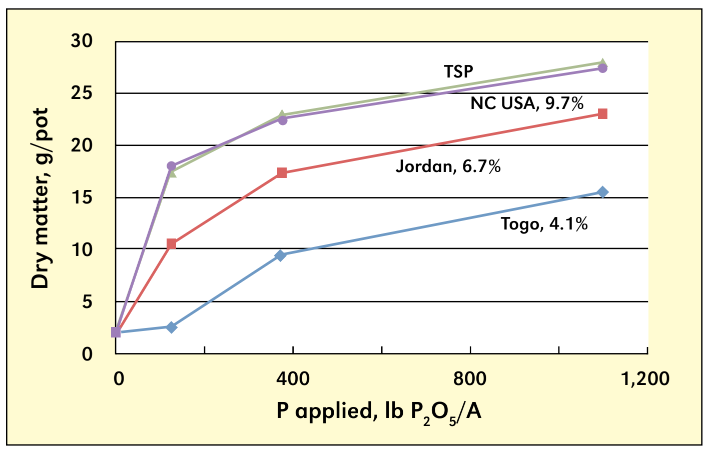


Figure 1. Dry-matter yield of maize fertilized with ground phosphate rock varying in neutral ammonium citrate solubility, compared with a soluble P source (TSP) in an acid soil (pH 4.8) (Chien and Friesen, 1992). The citrate solubility of each PR source is shown as percent P_2O_5.

Soil Properties

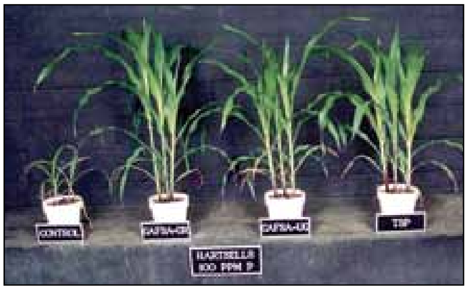
pH Among the soil properties, pH has the greatest influence on the agronomic effectiveness of PR. Chien (2003) reported that the relative agronomic effectiveness (RAE) of a highly reactive Gafsa PR (Tunisia) compared to TSP (RAE = 100%) increases as soil pH dropped in 15 soils with widely varying properties. However, soil pH alone was able to explain only 56% of variability of RAE in this study (Equation 1). By also considering the clay content (related to soil pH buffering capacity and cation ion exchange capacity), it is possible to explain 74% of variability of RAE (Equation 2). Since pH is a logarithmic scale of acidity, the agronomic effectiveness of PR sharply decreases as soil pH increases above 5.5. Therefore, the agronomic value of PR diminishes above this pH unless with an effective crop species.

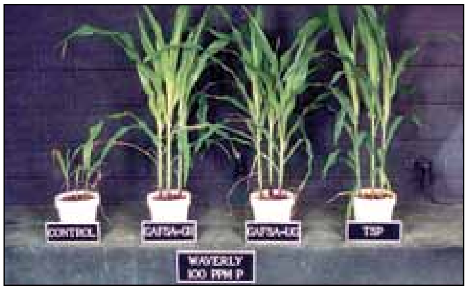
Equation 1: $\text{RAE, \%} = 181.4 - 21.1\,\text{pH} \quad (R^2 = 0.56)$

Equation 2: $\text{RAE, \%} = 163.4 - 20.6\,\text{pH} + 0.78\,\text{clay} \quad (R^2 = 0.74)$

Soil P-fixing capacity The release of P from PR generally increases with a greater P-fixing capacity of the soil. Adsorption and precipitation of soluble P provide a sink that favors PR dissolution. However, as the soil P-fixing capacity increases, the concentration of soluble P released from PR may initially decrease more rapidly than that from WSP sources, despite the fact that the dissolution of PR increases with an increase of soil P-fixing capacity. The negative effect of soil P-

Abbreviations: P = phosphorus; Al = aluminum; Ca = calcium.





These photos compare the effect of ground (GR) and unground (UG) PR on corn growth in two soils (Hartsells, pH = 4.8; Waverly, pH = 5.3). The Gafsa (Tunisia) PR is compared with TSP and an unfertilized control in the greenhouse.

fixing capacity on RAE of PR may be most significant for short-term crops, such as some vegetables. For long-term crops or residual short-term crops, RAE of PR compared to WSP tends to increase with increasing soil P-fixing capacity. **Figure 2** shows that the RAE of multiple PR sources varying in reactivity increases from the first bean crop to the third crop grown on soil with a high P-fixing capacity (Chien, 2003). This is due to (1) the residual effect of TSP decreases rapidly in soils with high P-fixing capacity, and (2) slow dissolution of PR in the soil with time.

Presence of Ca and organic matter Since dissolution of PR also releases Ca, soils with high initial Ca content typically have slower PR dissolution, according to the mass action law. For many tropical acid soils, exchangeable Ca is low and thus provides favorable conditions for PR dissolution. The positive influence of soil organic matter on increasing the agronomic effectiveness of PR has also been reported (Chien, 2003). Enhanced dissolution of PR due to formation of a chemical complex between soil organic matter and Ca^{2+} ions is proposed to be the mechanism.

Management Practices

The most effective way to apply PR is to broadcast it onto the soil, followed by incorporation with tillage. This technique maximizes the reaction of PR with the soil and minimizes interaction between PR particles. Band application of PR is not recommended because it limits the contact of PR particles with the soil, resulting in reduced dissolution. The effectiveness of PR is also reduced by granulation of fine particles (Chien, 2003).

Management of PR application for flooded rice requires special attention because soil pH generally increases upon flooding. The agronomic effectiveness of reactive PR can be drastically reduced when it is applied at or after flooding, whereas the PR can perform well when applied to the soil at least 2 weeks before flooding (Chien, 2003).

Adding limestone to acid soils is a common practice to raise soil pH and decrease Al toxicity. However, the increased pH and additional Ca from the lime are both detrimental to PR dissolution. Therefore, liming practices should balance the need to alleviate the Al toxicity with reducing PR dissolution (Chien and Friesen, 1992). It is recommended that liming to increase soil pH be limited to a range of pH 5.2 to 5.5 in order

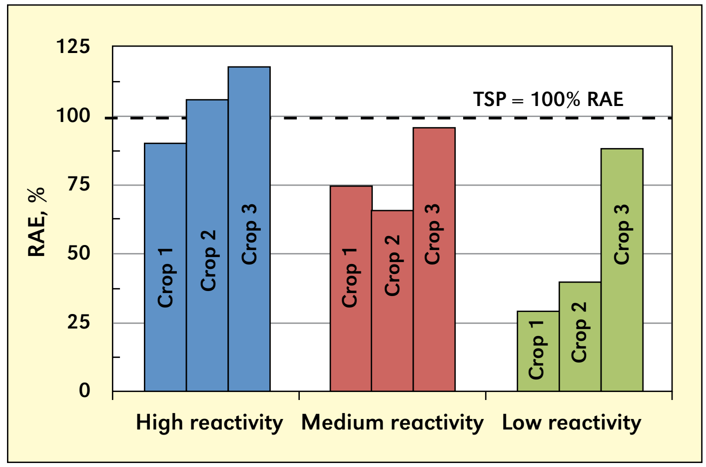


Figure 2. Relative agronomic effectiveness (RAE) of multiple PR sources (varying in solubility) on the seed yield of three successive bean crops grown on an Andosol in Colombia (Chien, 2003). RAE is calculated by comparison with TSP. All PR sources were applied one time at a rate of 410 lb P_2O_5/A.

to optimize the agronomic effectiveness of PR.

Crop Species

The usefulness of PR as a nutrient source varies with the crop species. In general, the effectiveness of PR is higher for long-term or perennial crops than for short-term or annual crops. PR has been used extensively for many tree crops in Asia, including rubber, oil palm, and tea. Use of PR for perennial pastures has been successful too.

Acidification in the plant rhizosphere accounts for some of the differences among crop species to utilize PR. In a study using six plant species, Van Ray and Van Diest (1979) found that Gafsa PR (Tunisia) was equivalent to TSP for buckwheat, which produced much lower rhizosphere pH than did other plant species.

Among the crop species, rape (canola) is known to be efficient in utilizing PR. Root exudation of organic acids is thought to contribute to PR dissolution. Habib et al. (1999) reported that rape was able to utilize a medium-reactive Ain Layloun PR (Syria), even in calcareous soils. Subsequently, Chien et al. (2003) found that the RAE of nine PR sources for rape grown on an alkaline soil (pH 7.8) increased from 0% to 88% as the 2% citric acid (CA) solubility of PR increased from 2.1% to 13.1% P_2O_5 **(Table 2)**.

Use of Phosphate Rock for Organic Farming

PR is sometimes used for direct soil application in organic farming systems. The success of PR for organic crop nutrition largely depends on its reactivity in the soil. The total P_2O_5 content provided on the package label is irrelevant to PR reactivity in the soil. In fact, most igneous PR sources are high in P_2O_5 content (>34%), but very low in reactivity due to little CO_3/PO_4 substitution in apatite mineral structure, and therefore not suitable for direct application in organic farming (Chien et al., 2009). However, details regarding the reactivity of PR are rarely provided for organic growers.

Factors affecting the effectiveness of PR for organic farming should be considered more or less the same way as for conventional farming. One exception is when PR is added

Table 2. Characteristics of different P sources and their relative agronomic effectiveness (RAE) for rape grown on an alkaline soil (pH 7.8) to maturity (Chien et al., 2003).

P source	Total P_2O_5 [1]	Solubility in 2% citric acid, %	Reactivity class[2]	RAE, %
TSP	46.2	100	-	100
Gafsa PR (Tunisia)	30.1	13.1	High	88
Ain Layloun PR (Syria)	28.1	12.2	Medium high	82
Chelesai (Kazakhastan)	17.0	10.0	Medium	74
Tilemsi PR (Mali)	26.2	10.3	Medium	72
El-Hassa (Jordan)	31.3	9.0	Medium	64
Kenegesepp (Russia)	29.9	7.8	Medium low	64
Kadjari (Burkina Faso)	25.3	6.0	Low	60
Kaiyang (China)	32.4	5.1	Low	42
Panda Hills (Tanzania)	24.8	2.1	Very low	0
Check	-	-	-	0

[1]As percent P_2O_5 of rock.
[2]Based on CO_3/PO_4 substitution in apatite structure.

during composting, where conditions may result in an alkaline rather than acidic environments (Chien et al., 2009) and the chelation of organic matter with Ca ions derived from apatite may be important to dissolve PR.

Phosphate Rock Decision Support System (PRDSS)

Many global agronomic trials with PR have been integrated into a single tool to predict its agronomic effectiveness in specific situations. IFDC (An International Center for Soil Fertility and Agricultural Development), in collaboration with FAO/IAEA (Food and Agriculture Organization/International Atomic Energy Agency), developed and published a PRDSS model for PR sources (Smalberger et al., 2006; >http://www-iswam.iaea.org/dapr/srv/en/dapr/home<). The PRDSS can be used in making decisions between use of WSP fertilizers and PR to meet crop nutrition needs. The PRDSS also provides assistance to determine conditions where the use of PR is more economical than WSP as a source of plant nutrients.

Conclusions

The agronomic and economic effectiveness of PR can be equivalent to or better than WSP fertilizers in some circumstances. Unlike WSP fertilizers, which can be widely used, there are specific factors – including the reactivity of PR sources, soil properties, management practices, and crop species – that must be taken into account in order to maximize the utilization of PR. Use of the PRDSS model is an effective means to predict the best use of this nutrient resource. BC

Response of soybeans to P source in Brazil.

Dr. Chien (nchien@comcast.net) was Principal Scientist–Soil Chemistry (retired), formerly with IFDC, Muscle Shoals, Alabama. Dr. Prochnow (lprochnow@ipni.net) is Director, IPNI Brazil Program, Piracicaba, SP, Brazil. Dr. Mikkelsen (rmikkelsen@ipni.net) is Director, IPNI Western North America Region, located in Merced, California.

References

Chien, S.H. 2003. Factors Affecting the Agronomic Effectiveness of Phosphate Rock for Direct Application. *In* Direct Application of Phosphate Rock and Related Technology: Latest Development and Practical Experiences, pp.50-62, (S.S.S. Rajan and S.H. Chien, ed.). Special Publications IFDC-SP-37, IFDC, Muscle Shoals, Alabama.

Chien, S.H., and D.K. Friesen. 1992. Phosphate Rock for Direct Application. *In* Workshop on Future Directions for Agricultural Phosphorus Research, pp. 47-52, TVA Bull. Y-224. Tennessee Valley Authority, Muscle Shoals, Alabama, U.S.A.

Chien, S.H., G. Carmona, J. Henao, and L.I. Prochnow. 2003. Commun. Soil Sci. Plant Anal. 34:1825-1835.

Chien, S.H., L.I. Prochnow, and H. Cantarella. 2009. Adv. Agron. 102:261-316.

Habib, L., S.H. Chien, G. Carmona, and J. Henao. 1999. Commun. Soil Sci. Plant Anal. 30:449-456.

Smalberger, S.A., U. Singh, S.H. Chien, J. Henao, and P.W. Wilkens. 2006. Agron. J. 98:471-483.

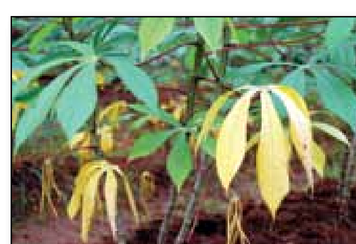
Van Ray, B. and A. Van Diest. 1979. Plant Soil 51: 577-589.

Crop Nutrient Deficiency Photo Contest Entries Due by December 15

December 15, 2010, is the deadline for entries in the annual IPNI contest for photos showing nutrient deficiencies in crops. There are four categories: Nitrogen (N), phosphorus (P), potassium (K), and Other (secondary nutrients and micronutrients).

Preference is given to original photos with supporting/verification data. Cash prizes are offered to First Place (USD 150) and Second Place (USD 75) in each of the four categories, plus a Grand Prize of USD 200 will be provided to best overall photo.

Entries can only be submitted electronically. For details and instructions, visit this website: >www.ipni.net/photocontest<.



Precision Management of Root Zone Potassium for Corn: Considerations for the Future

By T.S. Murrell and T.J. Vyn

Precision technologies allow fertilized soil volume to be managed over time to create zones of higher fertility, but just how this should be done for optimum short-term and long-term crop response is not well understood. Relevant considerations for K fertilizer placement include the persistence of increased fertility after banded applications as well as the redistribution of K within the soil that occurs simply under normal crop development. Research indicates that the location of prior crop rows may be even more important to soil K levels than the location of past fertilizer K bands.

Precision guidance systems are capable of a very high level of repeatable accuracy in geo-positioning. Currently available equipment advertises 1 in. pass-to-pass accuracy. These technologies, in conjunction with geographic information system software, allow all equipment passes to be spatially referenced, recorded, and stored.

Such capabilities provide new opportunities to manage nutrient applications, particularly those that are banded separately from (e.g. deep banding with strip tillage), or in conjunction with, crop planting operations. Instead of settling for a random array of past band applications in the field and limited knowledge of their exact location, farmers can now decide where future fertilizer should be banded in relation to past bands. If desired, farmers can place fertilizer in the same band year after year or offset bands from one year to the next at any desired distance from one another. Consequently, subsurface fertilized soil volume can be managed more precisely than before. It is not clear, however, how bands should be managed over time to maximize profitability and productivity.

This article focuses on considerations for managing banded K applications over time for corn. Unlike N and P, localized placement of K does not cause roots to proliferate in enriched zones (Claassen and Barber, 1977). Consequently, if roots are to take full advantage of a concentrated supply of K in a band, either N, P, or both may need to be co-applied.

A question being addressed in current tillage and K placement research is how much of the soil volume needs to be fertilized to maximize corn yield. Some insight into the answer to this question was provided by Claassen and Barber (1977). In their growth chamber studies of young corn plants grown in pots, it was found that 17-day-old corn plants, on average, had maximum above-ground biomass accumulation when at least 50% of the soil volume was fertilized with K (**Figure 1**). Translating these results to the field, however, is not straightforward, given the variability in rooting depth and other factors in present-day high plant density environments as well as the need to evaluate the cumulative effects over the entire growing season.

The prevalence of conservation tillage systems has led to nutrient stratification in many fields, where both P and K are more concentrated near the surface than deeper in the soil profile (Robbins and Voss, 1991). Moncrief et al. (1985) showed that stratification occurs quickly in reduced tillage systems where broadcast fertilizer K is applied. In his study examining spring K applications in both no-till and spring chisel/field cultivator systems, higher ammonium acetate extractable K levels near the surface were measured 2 months after application. Differential soil test K stratification in the 0 to 2, 2 to 4, and 4 to 8 in. depths due to spring tillage systems (no-till, strip-till, and field cultivator) in the prior corn year were also observed just 12 months after both broadcast and deep banded application of 150 lb K_2O/A (Yin and Vyn, 2004).

Abbreviations: K = potassium; N = nitrogen; P = phosphorus; ppm = parts per million.

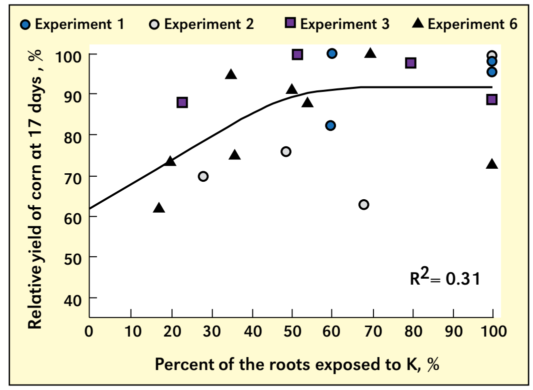


Figure 1. Relationship between relative yield of above-ground biomass of 17-day-old corn plants and the percent of roots exposed to K (Claassen and Barber, 1977).

Higher soil test P and K levels near the surface in reduced tillage systems appears to be among the list of possible factors altering corn root distribution in the soil profile. In a Minnesota study (Bauder et al., 1985), root distribution was compared among several different tillage systems during the summer. In the upper 3 in. of soil, no-till and ridge-till had higher root length densities and greater calculated root lengths than where soil had been moldboard plowed or chiseled. In addition, most of the roots were located directly below the row, with very few of them 7.5 to 15 in. away. Compared to no-till, chisel tillage, and moldboard plowing, ridge-till had the greatest overall root length and the greatest penetration of roots through the soil profile. In contrast, no-till had the greatest root length density below the row at the shallowest depth and the lowest root length density in all lower layers.

Stratification of nutrients, along with changes in root distribution with various tillage systems, has led researchers to investigate if there is any advantage to increasing the volume of fertilized soil in the likely rooting zone with bands at various depths. Although banded K applications made at the start of a season initially create concentrated zones in the soil, these zones may not be detectable by the end of the season when soil sampling is conducted. Low rates of K, like those found in starter fertilizer formulations, may be too low to provide long-lasting fertility increases unless they are applied repeatedly in the same areas over time. In a study examining the effects of 25 years of N-P-K applications banded 2 in. to the side and 2 in. below the corn seed at rates ranging from 11 to 23 lb K_2O/A/yr (Duiker and Beegle, 2006), only a slightly enriched zone next to the row was detected under chisel/disk tillage. Soil was sampled at 0 to 2, 2 to 4, and 4 to 6 in. depth increments along transects perpendicular to rows. In the other two tillage treatments examined, no-till and moldboard/disk, no enriched zone was detected where the starter fertilizer had been applied. This was in contrast to P, where distinct zones were found in all three tillage treatments. Instead, the most concentrated zone in the soil following grain harvest was in the corn row. In studies from Iowa, enriched K zones in the corn row were detected in both chisel-disk and no-till systems after 4 years of annually deep banded K (Mallarinio and Borges, 2006). Bands were placed 5 to 7 in. deep in the spring prior to tillage and applied at a rate of 70 lb K_2O/A/yr. Corn was planted directly over the bands. Enriched zones in the row were detected consistently in both tillage systems at the 2 to 6 in. depth increment. Recently collected data from Indiana in a strip-till corn followed by no-till soybean system **(Figure 2)** shows higher K concentrations in the corn row than between rows where K had been both broadcast or deep banded. Interestingly, the same effect was observed where no K had been applied (Vyn, 2010).

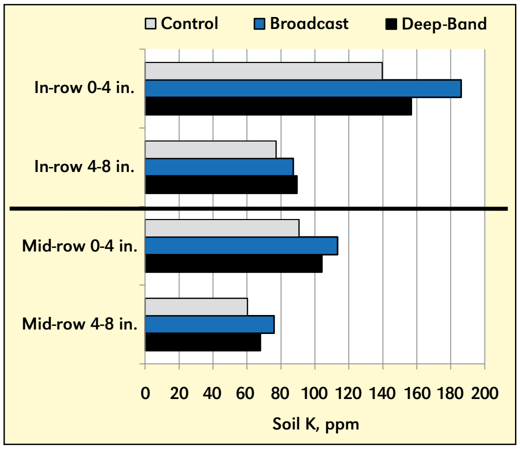


Figure 2. Soil K concentrations in spring 2008 following the third strip-till corn cycle for a corn-soybean rotation involving 30 in. strip-till corn and 15 in. no-till soybean.

Whether or not banded applications of K result in detectable zones of higher fertility may be influenced greatly by the growth of the corn crop itself. **Figure 3** shows estimates of the quantities of K taken up, removed by crop harvest, and returned to the soil through leaching by a 200 bu/A corn grain crop. The assumptions made were as follows: a) crop removal was 0.27 lb K_2O/bu; b) total above-ground plant uptake was 1.37 lb K_2O/bu; and c) leached K from the stover was the difference between total uptake and crop removal. Estimating K leached from the roots relied on estimates made by Amos and Walters for root dry matter production per plant (Amos and Walters, 2006). Grain test weight was assumed to be 56 lb/bu at 15.5% moisture. Grain yield (bu) was then converted to dry matter weight (lb). A harvest index of 0.5 was then assumed, resulting in an estimate of stover dry matter production equivalent to that of grain. This estimate included the cob weight. To subtract the cob weight, it was assumed that the cob represented 15% of the total stover dry weight. After subtracting the cob weight, the stover (minus the cob) weight was obtained. The ratio of 0.16 root:stover (minus cob) dry matter was then used to estimate total root dry weight per acre. Root K concentrations provided in Claassen and Barber (1977) were averaged and found to be 3%. This percent K was then multiplied by the total root dry weight per acre and converted to K_2O. The resulting estimates show that of the total K taken up by the above ground plant portions, most of it (approximately 80%) is returned to the soil surface through leaching from the stover.

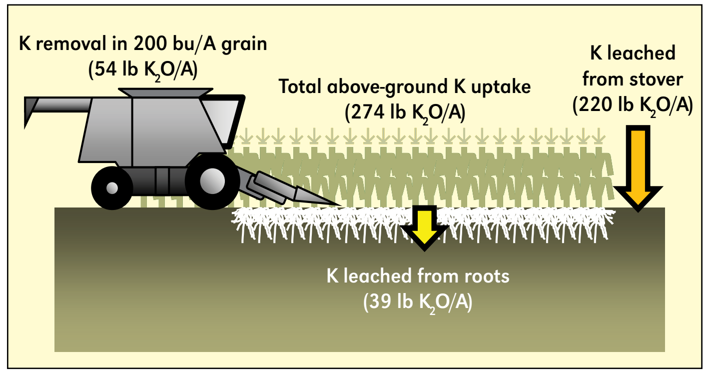


Figure 3. Estimated quantities of K_2O removed from the field with grain harvest as well as returned to the soil from the corn plant through leaching of K from corn stover and roots. Quantities are for 200 bu/A corn grain.

The amount of K estimated to be redistributed in the soil by the root system is 72% as much as was removed by the grain.

The quantities of K redistributed in the soil by the plant are significant compared to the quantities of K banded in the studies reported above. Consequently, it is not clear how much of the measured increases of K in the row are due to banding or simply to the redistribution of K by the corn plant itself. Some insight into this can be gained from the strip-till study from Indiana (Vyn, 2010) and an earlier no-till study from Ontario (Yin and Vyn, 2003), where higher concentrations of K were observed in the row compared to between rows, regardless of whether any K had been applied. It would seem, therefore, that redistribution of K by the plant is a major cause of higher K concentrations measured in the row and, as was the case in the Pennsylvania study (Duiker and Beegle, 2006), may make residual fertility impacts of lower, banded rates undetectable.

Precision guidance technology offers many opportunities to manage banded K applications in a number of configurations over time to create zones of higher fertility. Because the crop itself is capable of concentrating large quantities of K in the row, both at the surface and below, offsetting rows from year to year may be a viable strategy to keep K more distributed across the field over time. For instance, a second season of corn might be grown in rows placed in the middle of previous rows, with the next corn crop placed back on the original rows. The purpose of any row movement and K band movement strategy is to keep fertilized soil volumes higher over time to maximize grain yield. BC

Dr. Murrell is Director, IPNI North Central Region, North American Program, located at West Lafayette, Indiana; e-mail: smurrell@ipni.net. Dr. Vyn is Professor of Agronomy, Purdue University, West Lafayette, Indiana; e-mail: tvyn@purdue.edu.

References

Amos, B. and D.T. Walters. 2006. Soil Sci. Soc. Am. J. 70:1489-1503.
Bauder, J.W., G.W. Randall, and R.T. Schuler. 1985. J. Soil Water Conserv. 40:382-385.
Duiker, S.W. and D.B. Beegle. 2006. Soil Tillage Res. 88:30-41.
Claassen, N. and S.A. Barber. 1977. Agron. J. 69:860-864.
Mallarino, A.P. and R. Borges. 2006. Soil Sci. Soc. Am. J. 70:702-707.
Moncrief, J.F., P.M. Burford, and J.B. Swan. 1985. J. Fert. Issues 2:17-25.
Robbins, S.G. and R.D. Voss. 1991. J. Soil Water Conserv. 46:298-300.
Vyn, T.J. 2010. Personal communication.
Yin, X. and T.J. Vyn. 2003. J. Plant Nutrition 26: 1383-1402.
Yin, X. and T.J. Vyn. 2004. Soil Tillage Res. 75: 151-159.

On-farm Evaluation of Real-time Nitrogen Management in Rice

Harmandeep Singh, K.N. Sharma, Gagandeep Singh Dhillon, Amanpreet, Tejdeep Singh, Vicky Singh, Dinesh Kumar, Bijay Singh, and Harmandeep Singh

On-farm trials were carried out to evaluate real-time and fixed-date variable rate strategies of need-based N management in rice using a leaf color chart (LCC) in relation to blanket recommendations for the State and farmer practice. The strategy of fixed-date variable rate N management produced yields similar to those obtained with the real-time N management or blanket recommendation strategies, although significant differences in N use efficiency were obtained.

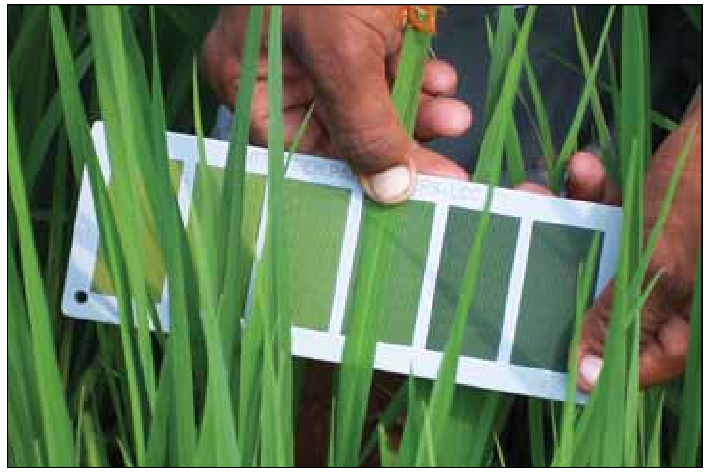
Current fertilizer N recommendations in India typically consist of fixed rate and timings for large rice growing tracts. These "blanket" recommendations have served their purpose in producing good yields, but they are limited in their capacity to increase nutrient use efficiency. And many times, to ensure high yields, farmers apply fertilizer N rates even higher than the blanket recommendation. Over-application of N in cereal crops leads to further lowering of N fertilizer recovery efficiency. The blanket recommendations are also not responsive to temporal variations in crop N demand.

Use of N in excess of crop requirement and inefficient splitting of N applications are the main reasons for low N use efficiency in rice. Since improving the synchrony between crop N demand and the N supply from soil and/or the applied N fertilizer is likely to be the most promising strategy to increase N use efficiency, the split application of fertilizer N is going to remain an essential component of fertilizer N management strategies in rice. Real-time corrective N management is based on periodic assessment of plant N status, and the application of fertilizer N is delayed until N deficiency symptoms start to appear. Thus, a key ingredient for real-time N management is a method of rapid assessment of leaf N content that is closely related to photosynthetic rate and biomass production and is a sensitive indicator of changes in crop N demand within the growing season.

As rice leaf color is a good indicator of leaf N content, the LCC, developed through collaboration of the International Rice Research Institute (IRRI) with agricultural research systems of several countries in Asia, serves as a visual and subjective indicator of plant N deficiency. With its 4- or 6-color panels of different shades of green, the LCC is used as a reference tool and is becoming popular as an inexpensive and easy-to-use tool for estimating leaf N content and managing fertilizer N in rice.

LCC-based, real-time N management can be practiced in rice by monitoring leaf color at 7- to 10-day intervals during the growing season. Fertilizer N is applied whenever the leaves are less greenish than a threshold LCC value, which corresponds to a critical leaf N content (Bijay-Singh et al., 2002, Varinderpal-Singh et al., 2007, Yadvinder-Singh et al., 2007). Many times, farmers prefer less frequent monitoring of leaf color as they are strongly accustomed to applying fertilizer N at growth stages as per the blanket recommendation. An alternative fixed-time option involves application of moderate rates of N at transplanting, and at 21 days after transplanting (DAT), coupled with monitoring of leaf color only at panicle initiation around 42 DAT and applying fertilizer N as guided by the leaf color ... all critical growth stages requiring a sufficient supply of N. Applications of fertilizer N can be adjusted upward or downward based on leaf color, which reflects the crop's relative need for N. We conducted on-farm trials during two rice seasons to evaluate both approaches relative to the blanket recommendation and farmer practice of applying fertilizer N to rice.

Abbreviations: N = nitrogen.



This is an example of the 6-color LCC used in gauging rice leaf color.

On-farm field trials were carried out in different districts in Punjab, India, during the 2008 and 2009 rice seasons. A 6-panel LCC manufactured by Nitrogen Parameters, Chennai, India, was used for evaluating N status of rice leaves as defined by their greenness. At each site, fields varying from 1,000 to 2,000 m^2 in size were divided into four plots in which fertilizer N was applied as per the following strategies:

1. Farmer fertilizer practice
2. Blanket fertilizer recommendation: 120 kg N/ha in three equal split rates at transplanting and 21 and 42 DAT
3. Real-time N using LCC: A basal dose of 30 kg N/ha + 30 kg N/ha whenever color of the first fully opened leaf from the top was less than shade 4 of the 6-color panel LCC; starting 15 DAT up to initiation of flowering
4. Fixed-date variable rate N management: 30 kg N/ha basal + 40 kg N/ha at 21 DAT + 30 or 45 kg N/ha at 42 DAT depending upon leaf color being > or < than shade 4 of the 6- color panel LCC

The amount of fertilizer N applied at different dates within the four treatments was recorded.

In 2008, 30-to-35 day old rice seedlings were transplanted at different field locations during June 25 to July 1. In 2009,

Table 1. Evaluating real time N management and fixed time variable dose N management strategies using leaf color chart vis-à-vis farmer fertilizer practice and blanket recommendation in rice at on-farm locations in Punjab, India, during 2008 and 2009.

	Farmer fertilizer practice		Blanket fertilizer recommendation[1]		Real-time N management using LCC[2]		FDVR[3] (N_{30} + N_{40}+ $N_{30/45}$)	
Village /district	Fertilizer N applied, kg/ha	Grain yield, t/ha	Fertilizer N applied, kg/ha	Grain yield, t/ha	Fertilizer N applied, kg/ha	Grain yield, t/ha	Fertilizer N applied, kg/ha	Grain yield, t/ha
2008 rice season								
Mrar Kalan, Muktsar	133	7.38	120	7.50	90	7.20	115	7.55
Pakhi Kalan, Faridkot	153	8.80	120	8.40	90	8.48	115	8.55
Hakumat Singh Wala, Ferozepur	150	8.40	120	8.30	120	8.53	115	8.33
Chuhana, Gurdaspur	146	6.05	120	5.98	90	5.88	115	6.00
Kala Manjh, Hoshiarpur	150	7.13	120	7.00	120	6.83	115	7.00
2009 rice season								
Tehna 1, Faridkot	180	7.40	120	6.80	90	6.90	115	6.95
Tehna 2, Faridkot	169	6.80	120	7.00	90	6.80	115	6.80
Pakka 1, Faridkot	135	8.00	120	7.60	60	7.20	100	7.40
Pakka 2, Faridkot	127	6.00	120	7.20	90	7.00	115	7.00
Wara Draka, Faridkot	115	8.00	120	9.00	90	8.80	115	9.00
Dusanjh, Moga	180	7.35	120	8.00	60	7.80	100	8.05
Bhaloor, Moga	180	6.80	120	6.40	90	6.30	115	6.30
Samalsar, Moga	160	7.80	120	7.20	90	7.28	100	7.15
Wara Bhai Ka 1, Ferozepur	116	7.20	120	7.28	60	7.15	100	7.20
Wara Bhai Ka 2, Ferozepur	140	6.00	120	6.00	90	5.85	115	5.95

[1] 120 kg N/ha in three equal split rates at transplanting and 21 and 42 DAT.
[2] Basal rates of 30 kg N/ha + 30 kg N/ha whenever color of the first fully opened leaf from the top was less shade 4 of the LCC; starting 15 DAT up to initiation of flowering.
[3] Fixed-date variable rate N management: 30 kg N/ha basal + 40 kg N/ha at 21 DAT + 30 or 45 kg N/ha at 42 DAT depending upon leaf color to be ≥ or < than LCC shade 4.

transplanting dates were between June 17 and July 15. The experimental soils had pH values (soil: water 1: 2) ranging from 7.7 to 8.7, organic carbon ranging from 0.22 to 0.56%, and texture ranging from sandy loam to clay loam. The names of villages and districts where different trials were established are listed in **Table 1**. The experiments were harvested from October 3 to October 30 in 2008 and from October 10 to November 01 in 2009. An area ranging from 40 to 60 m^2 in the centre of each treatment plot was used to estimate grain yield (14 % moisture) at harvest.

Results

Compared to the blanket fertilizer N recommendation of 120 kg N/ha, the 15 farmers following their own practice applied 115 to 180 kg N/ha to rice **(Table 1)**. Except for two farmers who applied 115 and 116 kg N/ha, all others applied substantially higher amounts of fertilizer N to rice. While in the fixed-date variable rate treatment one could apply either 100 or 115 kg N/ha, fertilizer N rates in the leaf color-based, real-time fertilizer N management treatment varied from 60 to 120 kg N/ha.

Grain yields recorded were similar across four strategies at all locations, thus revealing that higher amounts of N application as per farmer fertilizer practice compared to the three other strategies (i.e., blanket, real time, and fixed-date variable rate) were not advantageous. The grain yields recorded in the LCC-based real-time N management and fixed-date variable rate strategies were similar to those obtained with the blanket rate of 120 kg N/ha at all 15 locations. These results from the real-time N management strategy were obtained by applying 60 to 120 kg N. This large variation in N application rates suggests that the strategy can guide N application to rice as per need of the crop while not adversely affecting yield.

Partial factor productivity (PFP_N), a measure of N use efficiency defined as yield of harvested portion divided by amount of N fertilizer applied (Snyder and Bruulsema, 2007) is plotted as an average for each treatment across sites in **Figure 1**. Real-time N management performed the best, while the fixed-date variable N rate application appears to hold promise despite needing further refinement. These results are in-line with those reported by Varinderpal-Singh et al. (2007) and Yadvinder-Singh et al. (2007) from other on-farm locations in Punjab. Although yield levels obtained by following the

Blanket N recommendations cannot achieve the N use efficiency of real-time split applications based on monitoring.

The LCC is gaining in popularity as an inexpensive tool for estimating leaf N content and managing fertilizer N in rice.

fixed-date variable rate strategy were similar to those recorded for real-time N management, the former allowed application of either 100 or 115 kg N/ha compared to the 60 to 120 kg N/ha range in the latter. This suggests that fixed-date variable N application, as was designed in this study, needs to be modified to allow for N application across a wider seasonal range. It is proposed here that this can be done either by introducing the element of variable rate N application at the 21 DAT stage or by including another date for fertilizer application as per leaf color just before flowering (around 60 days).

Conclusions

In summary, farmers had a general tendency towards applying up to 60 kg N/ha more fertilizer N than the blanket recommendation of 120 kg N/ha without capturing a yield benefit. Real-time N management based on applying fertilizer N whenever leaf color was less than critical greenness resulted in application of 60 to 120 kg N/ha with rice yields being equivalent to those obtained with the blanket recommendation. Following the strategy of fixed-date variable rate N management, either 100 or 115 kg N/ha was applied, and yields were equal to those produced by real-time N management or the blanket recommendation. For easy adoption by farmers, the fixed-date variable rate strategy needs to be modified to allow the application of N across a wider seasonal range. BC

Mr. Harmandeep Singh is Research Fellow in the Department of Soils, Punjab Agricultural University, Ludhiana 141 004, Punjab; e-mail: harman_80fdk@rediffmail.com. Dr. Sharma is Professor, Department of Soils, Punjab Agricultural University, Ludhiana 141 004, Punjab, e-mail: sharma_kn@rediffmail.com. Mr. Dhillon, Ms. Amanpreet, Mr. T. Singh, and Mr. V. Singh are Research Fellows in the Department of Soils, Punjab Agricultural University, Ludhiana 141 004, Punjab; e-mail: preetaman_13@yahoo.co.in. Dr. Kumar is Associate Professor, Department of Soils, Punjab Agricultural University, Ludhiana 141 004, Punjab; e-mail: dinesh_kathuria@rediffmail.com. Dr. B. Singh is National Professor, Indian Council of Agricultural Research (ICAR), at Punjab Agricultural University, Ludhiana, e-mail: BijaySingh20@hotmail.com Dr. Harmandeep Singh is Deputy Director, West India Region, IPNI South Asia Program, e-mail: hsingh@ipni.net.

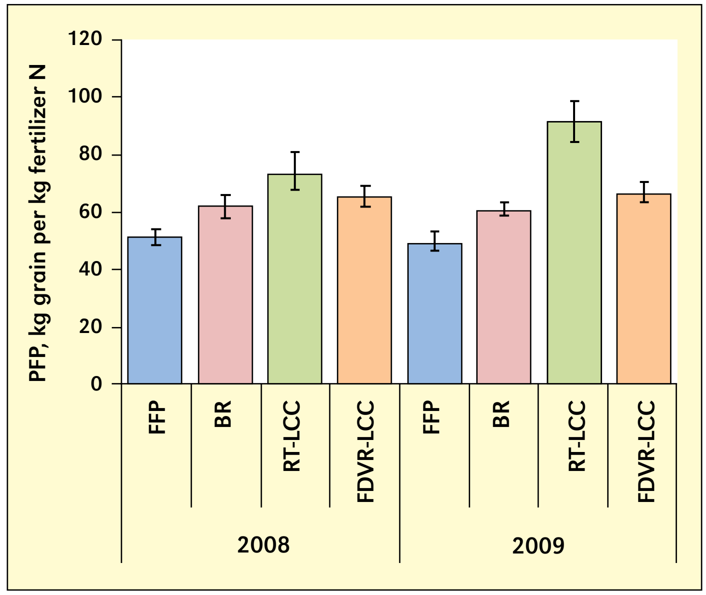


Figure 1. Partial factor productivity (PFP_N) of different N management strategies in rice averaged over 5 and 10 on-farm experiments in 2008 and 2009, respectively. [FFP = Farmer fertilizer practice; BR = Blanket recommendation; RT-LCC = Real time N management using leaf color chart; and FDVR-LCC = Fixed-date variable rate N management using LCC].

References

Bijay-Singh, Yadvinder-Singh, J.K.Ladha, K.F. Bronson, V. Balasubramanian, Jagdeep-Singh and C.S. Khind. 2002. Agron. J. 94:821-829.

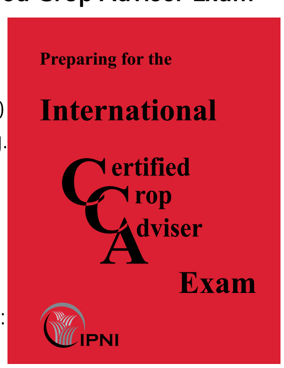
Snyder, C.S. and T.W. Bruulsema. 2007. International Plant Nutrition Institute. June 2007. Reference # 07076. Norcross, GA, U.S.A. pp. 4

Varinderpal-Singh, Yadvinder-Singh, Bijay-Singh, Baldev-Singh, R.K. Gupta, Jagmohan-Singh, J.K. Ladha, and V. Balasubramanian. 2007. Archives of Agron. and Soil Sci. 53: 567-579.

Yadvinder-Singh, Bijay-Singh, J.K. Ladha, J.S. Bains, R.K. Gupta, R.K., Jagmohan Singh, and V. Balasubramanian. 2007. Nutr. Cycl. in Agroecosys. 78:167-176.

Study Guide for International Certified Crop Adviser Exam

The publication titled *Preparing for the 2011 International Certified Crop Adviser Exam* (Item #50-1000) is available for purchase from IPNI. The price of USD 50.00 (fifty-dollars) includes shipping and handling. Contact: Circulation Department, IPNI, 3500 Parkway Lane, Suite 550, Norcross, GA 30092-2806. Phone: 770-825-8084; Fax: 770-448-0439; E-mail: circulation@ipni.net. The ICCA exam study guide may also be purchased on-line by visiting this website: >www.ipni.net/ccamanual<.



AG CONNECT Expo Set for January 2011

North America's new global agriculture exhibition, AG CONNECT Expo 2011, is set for January 8-10 (with preview day January 7) in Atlanta, Georgia. IPNI is a supporter and exhibitor for the event and will sponsor two educational presentations. AG CONNECT Expo is organized by the Association of Equipment Manufacturers, with direction from industry companies and organizations. For more information, visit the website: >www.agconnect.com<.

Effect of Unrestricted Nitrogen and Irrigation Application on Soil Carbon and Nitrogen Pools in Greenhouse Vegetable Systems

By S.J. Qiu and X.T. Ju

In the north China plain, the amount of N fertilizer and irrigation application in greenhouse vegetable systems is about three to five times that in conventional cereal systems. Over a decade of shifting from the conventional cereal systems to greenhouse vegetables, the capacity for nutrient cycling within these greenhouse systems has fallen. Additionally, the content of inorganic C in the soil profile under greenhouse systems has shown a dramatic decline.

Storage of soil organic carbon (SOC) and carbonate carbon (IC) in agricultural land can be influenced by management practices such as tillage, fertilizer N inputs, and crop rotations (Russell et al., 2005). Indeed, long-term over-use of fertilizer N in agricultural systems has resulted in substantial NO_3^- leaching and soil carbonate has become depleted as a result of soil acidification (Ju et al., 2007). Hence, changes in SOC and carbonate content with N fertilization can affect soil C stability.

The natural abundance of stable isotopes can be used as a measure to reflect soil C and N cycling and storage (Lynch et al., 2006). Differences in plant $\delta^{13}C$ can be attributed to differences in photosynthesis between C_3 and C_4 plants and differences in soil $\delta^{15}N$ can result from discrimination against ^{15}N during the N loss process (Lynch et al., 2006). Thus, it is possible to quantify changes in soil C and N pools after long term changes in crop species and fertilizer regimes.

Soil organic matter (SOM) can be differentiated into soil active pools and passive pools. The active SOM fractions respond very sensitively to management practices and affect nutrient (including N) supply (Wander, 2004). The character of the active SOM can be denoted by particulate organic matter (POM), soil microbial biomass C and N (SMBC, SMBN), and dissolved organic matter (DOM) because these pools bring together the physical, biological and chemical functions of SOM (Wander, 2004).

Greenhouse vegetable production has played an important role in increasing farming incomes during the last two decades.

The shift to greenhouse vegetable systems has resulted in some concerns for soil quality and nutrient cycling.

In Shouguang County of Shandong Province, more than 65% of the arable land is now used for intensive greenhouse production, with an average of 2,220 kg fertilizer N/ha and 1,800 mm irrigation water applied each year to two successive crops (He et al., 2007). However, the effects of these excessive N rates application and massive irrigation on the C and N pools of the local soils, which are low in SOC, have not yet been determined.

Abbreviations: C = carbon; N = nitrogen; NO_3-N = nitrate N; Ca = calcium; Mg = magnesium; NH_4 = ammonium.

Table 1. Farm management, yields, and pH distribution in the soil profiles of the sampling sites.

System[1]	Site	Year started	Crop rotation3	Fertilizer/manure[3] kg N/ha/yr	Irrigation[3] mm/yr	Yield[3] t/ha/yr	pH at different depths (cm) in the soil profile 0-10	10-20	20-40	40-60	60-80	80-100
[2]G1	Yingli	1996	Tomato/Cucumber	1,634/1,300	1,400-1,700	171.0	7.71	7.87	8.07	8.13	8.05	8.14
C1	Yingli	1978	Maize/Wheat	600/0	<300	16.5	7.97	8.15	8.22	8.28	8.51	8.55
G2	Yingli	1996	Tomato/Cucumber	1,572/1,246	1,500-1700	175.6	7.38	7.67	8.20	8.17	8.15	8.11
C2	Yingli	1978	Maize/Wheat	600/0	<300	17.0	7.84	7.97	8.18	8.22	8.23	8.35
G3	Tianliu	1993	Tomato/Cowpea	1,829/1,318	1,300-1700	168.4	5.59	5.53	5.58	7.21	7.31	7.60
C3	Tianliu	1978	Maize/Wheat	500/100	<300	18.0	7.89	8.22	8.30	8.22	8.02	8.02
G4	Tianliu	1993	Tomato/Sweet pepper	1,620/1,866	1,400-1,600	150.0	6.87	6.90	7.26	7.45	7.56	7.56
C4	Tianliu	1978	Maize/Wheat	500/100	<300	18.0	7.89	7.99	8.11	8.24	7.96	7.83

[1]G, Greenhouse system; C, Conventional cereal system.
[2]Yield in greenhouse system refers to fresh weight and that in conventional cereal system to air-dried weight.
[3]Date of acquisition: April 2007. The amount of fertilizer/manure is the sum of chemical fertilizer or manure from both crops, respectively.

Table 2. Storage of soil organic C (SOC), soil inorganic C (IC), total carbon (TC) and total N (TN) in the soil profile (0 to 100 cm) of greenhouse (G) and conventional cereal (C) production systems.

	SOC, t C/ha		ΔSOC, t C/ha/yr	IC, t C/ha		ΔIC, t C/ha/yr	TC, t C/ha		ΔTC, t C/ha/yr	TN, t N/ha		ΔTN, t N/ha/yr
Site	G	C	G - C	G	C	G - C	G	C	G - C	G	C	G - C
Yingli 1	95.5	68.6	2.46	360.7	399.3	-3.51	456.2	467.8	-1.05	14.6	8.8	0.53
Yingli 2	109.5	88.9	1.87	343.2	433.8	-8.24	452.7	522.7	-6.37	12.4	9.1	0.12
Tianliu 1	89.8	89.3	0.07	15.1	34.7	-1.40	104.9	124.0	-1.33	9.9	9.2	0.08
Tianliu 2	109.1	85.4	1.69	5.0	23.1	-1.30	114.1	108.6	0.39	9.4	6.7	0.10

Shouguang County (36°41´-37°19´N, 118°32´-119°10´E) has a typical continental monsoon climate with annual average air temperature and precipitation of 12.4 ºC and 558 mm, respectively. Conventional maize/wheat rotations have been practiced since 1978 and greenhouse vegetable production has developed rapidly in place of the cereal rotation since the 1990s. The details of N fertilizer and irrigation in greenhouse systems and conventional maize/wheat rotation systems are shown in **Table 1**.

Paired soil samples were taken from four greenhouses and adjacent conventional cereal fields for direct comparison of the two production systems at the end of April 2007. Two pairs of samples were collected from Yingli village (118°48´N, 37°03´E) and two from Tianliu village (118°47´N, 36°59´E). The sampling distance between each greenhouse and the adjacent field was <50 m, with >200 m between greenhouses at each site. A single field sample was a composite of at least eight soil cores representing approximately 400 m^2 of area. The 100 cm deep sample cores were divided into 0 to 10, 10 to 20, 20 to 40, 40 to 60, 60 to 80, and 80 to 100 cm depth increments. A 100 cm soil profile of a conventional cereal system, either at Yingli or Tianliu, was taken to measure soil bulk density at these same soil depths. With increasing soil depth, bulk density was 1.42, 1.45, 1.47, 1.45, 1.43, and 1.43 g/cm^3 at Yingli. At Tianlie, bulk density was 1.48, 1.50, 1.46, 1.42, 1.41, and 1.50 g/cm^3. Contents of SOC, NO_3-N, IC, and soil bulk density were also determined at each depth increment as was the concentration and natural abundance of POM. The concentration of SMBC, SMBN, and DOM were determined at 0 to 10, 10 to 20, and 20 to 40 cm depth categories.

Soil samples for SOC analysis were soaked for 24 h in excess 0.3 mol/L HCl solution to remove calcium carbonate ($CaCO_3$). The wet soil was cleaned with deionized water until the solution pH was above 6 and oven-dried at 60 °C. POM was determined as described by Bronson et al. (2004). TN, SOC, POM-C, and POM-N of soil passed through a 0.15-mm mesh were determined with a CN analyzer (Vario Max CN, Elementar, Germany). Both $\delta^{13}C$ and $\delta^{15}N$ were determined with a mass spectrometer (Delta Plus XP, Thermo Finnigan, Germany). The $\delta^{13}C$ values were expressed relative to Pee Dee Belemnite and $\delta^{15}N$ to atmospheric N_2 for N.

Soil NO_3-N was extracted with 1 mol/L KCl at a soil:water ratio of 1:5 (W/V) and measured with a continuous flow analyzer (TRAACS 2000, Bran and Luebbe, Germany). SMBC and SMBN were determined by the $CHCl_3$ fumigation-extraction (FE) method. Their C contents were determined with a TOC analyzer (Phoenix 8000, Tekmar, USA) and N contents were determined by continuous flow analyzer (FIA Star 5000, Foss, Sweden) following Kjeldahl digestion. The calculation details of SMBC and SMBN were shown by Wu et al. (1990). DOC and DON were determined according to Cookson et al., (2007). Soil carbonate C was determined by the pressure calcimeter method.

Data are expressed on oven-dried soil basis. Student's t-test was used to assess differences at the 5% level between greenhouse and conventional cereal system. Data are reported in this paper as the mean ± one standard error of the mean (SEM).

Carbon and Nitrogen

The storage of TC in the soils of the greenhouse system was less than in the conventional cereal system with the exception of the Tianliu 2 site **(Table 2)**. The Yingli and Tianliu sites had distinctly different IC contents, but across sites, greenhouse soils commonly showed a large decline in IC **(Table 1)**. For example, greenhouse production at Tianliu 2 was responsible, in part through soil acidification, for a 78% loss in soil IC.

In parts of Shandong Province, more than 65% of arable land is now used for intensive greenhouse production.

Soil acidification was likely the result of nitrification of large, repeated applications of NH_4-based N fertilizer and the leaching of NO_3-N under unconstrained irrigation regimes (Ju et al., 2007). Over the four pairs of samples, SOC summed over the whole profile was significantly different between the two production systems ($p < 0.05$; greenhouse: 101.0 ± 9.9 t C/ha, conventional system: 83.0 ± 9.8 t C/ha), which may be attributable to the numerous different types of manure incorporated into the soil to maintain high vegetable crop yields (He et al., 2007). No significant difference in TN was observed between the production systems ($p > 0.05$; greenhouse: 11.6 ± 2.4 t N/ha; cereal rotation: 8.5 ± 1.2 t N/ha), but the higher concentrations of TN in the greenhouse system may have resulted from the very high N fertilizer and manure applications (He et al., 2007).

Nitrate-N

The concentration of NO_3-N in the greenhouse soil was much higher than in the conventional system and the difference was significant below the 20 cm soil depth ($p < 0.05$; **Figure 1**). Soil NO_3-N as a percentage of TN was 6.0 to 10.0% at the

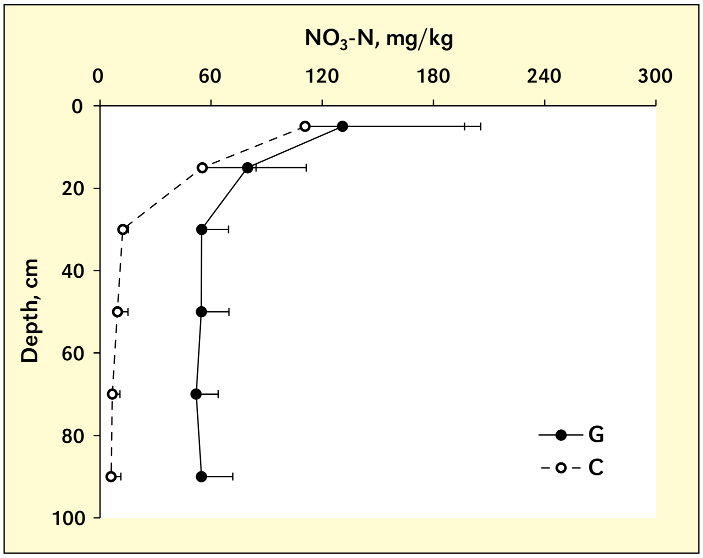


Figure 1. Concentrations of NO_3-N in the soil profile of a greenhouse (G) and a conventional (C) production system. Values at each depth are the mean of four sites considered as replicates. An asterisk represents a significant difference ($p < 0.05$) between greenhouse and conventional production systems.

0 to 100 cm depth in the greenhouse system and 1.2 to 8.1% in the conventional system. Soil NO_3-N summed over the whole profile in the greenhouse and conventional cereal system was 933 ± 265 and 339 ± 192 kg N/ha, respectively. Excessive NO_3-N leaching in the highly irrigated greenhouse system may have resulted in heavy pollution of groundwater, with the irrigation rate reaching 1,800 mm per year (He et al., 2007).

Active C and N Pools

Soil POM-C, POM-N, POM-C/SOC, and POM-N/TN in the top 40 cm of the soil profile were significantly higher in the greenhouse soil than the cereal soil (data not shown). Soil POM-C expressed as a percentage of SOC in the greenhouse system ranged between 24.3 and 52.4% and in the conventional system between 16.0 and 27.2%. Similarly, POM-N as a percentage of TN ranged from 14.0 to 31.7% and from 8.3 to 14.6%, respectively. The $\delta^{13}C$ of POM-C did not differ significantly between the two systems; $\delta^{15}N$ of POM-N was significantly higher in the greenhouses than in the cereal soil at the 0 to 20 cm depth ($p < 0.05$). Thus, the contribution of manure to POM-N was significantly greater ($p < 0.05$) than that to POM-C in the greenhouse system. Mendham et al. (2004) reported that a higher quality POM could lead to a decline in the net N mineralization rate. According to Wander (2004), the higher POM concentration in greenhouse system would indicate that manure application facilitated an increase in soil aggregation. However, for the greenhouse systems studied, the decline in soil carbonate discussed in **Table 2,** low SMBC/SOC, and low SMBN/TN (data not shown) all suggest that soil quality has deteriorated under these greenhouse crop production conditions.

Higher SOC and TN content combined with lower concentrations of SMBC and SMBN in the greenhouse system means that the capacity for nutrient cycling has decreased. Below the 10 cm soil layer, DOC/SOC in the conventional system was also significantly higher than in the greenhouse system (data not shown). The unrestricted manure applications and subsequent acidification of soil promotes the leaching of bridging cations (e.g. Ca^{2+}, Mg^{2+}) and further enhances the solubilization of organic matter (Zech et al., 1994).

Summary

The shift from the conventional cereal production system to intensive greenhouse vegetables has resulted in higher accumulation of NO_3-N, higher TN, and lower total C stocks due to a dramatic decline in carbonates in soil caused by intensive ammonium fertilization and unrestricted irrigation.Together this has lead to high nitrification rates and a large release of protons as well as a high potential for NO_3^- leaching. In both production systems, SOC in surface soil contained much more newly formed C sources (POM-C) and the $\delta^{15}N$ of POM-N responded sensitively to the effects of manure and chemical fertilizer application ($p < 0.05$). Soil quality may deteriorate in these greenhouse systems as measured by declines in SOC/TN ratios and SMBC/SOC and SMBN/TN ratios ($p < 0.05$). Besides, the high accumulation of NO_3-N presents a considerable danger for the quality of groundwater. BC

Taking soil samples to study changes.

Dr. Qiu is currently with Institute of Agricultural Resources and Regional Planning, CAAS, Beijing, 100081, China; e-mail: shjunqiu@caas.ac.cn. Prof. Dr. Ju is with the College Resources and Environmental Sciences, China Agricultural University, Beijing 100193, China; e-mail: Juxt@cau.edu.cn.

Acknowledgments

This work was supported by the National Natural Science Foundation of China (NSFC Grant no. 40771098), the 973 project (2009CB118606), the Sino-German Cooperative Project (DFG International Research Training Groups, GK1070), the '863' Project (2008AA06Z315), and the Innovative Group Grant of NSFC (no. 30821003).

References

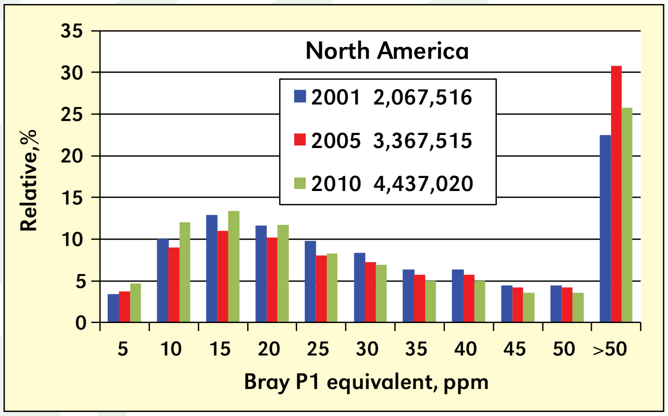
Bronson, K.F., T.M. Zobeck, T.T. Chua, et al. 2004. Soil Sci. Soc. Am. J. 68, 1695–1704.
Cookson, W.R., M. Osman, P. Marschner, et al. 2007. Soil Biol. Biochem. 39, 744–756.
He, F.F., Q. Chen, R.F. Jiang, et al. 2007. Nutr. Cycl. Agroecosyst. 77, 1–14.
Ju, X.T., C.L. Kou, P. Christie, et al. 2007. Environ. Pollut. 145, 497–506.
Lynch, D.H., R.P. Voroney, and P.R. Warman. 2006. Soil Biol. Biochem. 38, 103–114.
Mendham, D.S., E.C. Heagney, M. Corbeels, et al. 2004. Soil Biol. Biochem. 36, 1067–1074.
Russell, A.E., D.A. Laird,, T.B. Parkin, et al. 2005. Soil Sci. Soc. Am. J. 69, 413–422.
Wander, M. 2004. *In* Magdoff, F.R., Weil, R.R. (Eds.), CRC, Boca Raton, pp. 67–102.
Wu, J., R.G. Joergensen, B. Pommerening, et al. 1990. Soil Biol. Biochem. 22, 1167–1169.
Zech, W., G. Guggenberger, and H.R. Schulten. 1994. Sci. Total Environ. 152, 49–62.

THE FERTILITY OF NORTH AMERICAN SOILS – SUMMARY 2010

The 2010 IPNI summary of 4.4 million soil samples is probably the most comprehensive evaluation of soil fertility ever conducted in North America (NA). We said the same thing about the 2005 summary. Collectively, these two summaries examined nearly 8 million samples to offer a status report of one of the most precious natural resources of NA, its soil.

Submissions from laboratories indicate that use of soil testing has increased substantially since 2005. The 2010 summary gives a more complete evaluation of the components of soil fertility than previous summaries, providing information about phosphorus (P), potassium (K), sulfur (S), magnesium (Mg), zinc (Zn), chloride (Cl^-), and pH.

Phosphorus. The median P level for NA of 25 parts per million (ppm) indicates a 6 ppm decline from 2005. The region of most consistent P declines was the Corn Belt, which also experienced a decline of 6 ppm to a 2010 median level of 22. This decline has major agronomic significance since a high percentage of samples from this region now test below critical levels and call for annual P fertilization to avoid yield reductions. Soil P declines across the Corn Belt were correlated with P partial balances which were negative for the 5-year period for 10 of the 12 states. The Northeast continues to have some of the highest soil P levels in NA, usually associated with intensive livestock or vegetable production.



The median P level for NA (U.S. and Canada) declined from 31 ppm in 2005 to 25 ppm in 2010.

Potassium. The median K level for NA declined 4 ppm, an amount numerically similar to P decline – but at a median level of 150 ppm, the decline has much less agronomic significance. However, the current median is very close to what many recommendation systems consider to be an agronomic critical level for crop response. The western Corn Belt and much of the Great Plains and Northeast experienced significant soil K declines. Some of the apparent soil K changes are very likely due to factors other than nutrient management, such as weather patterns that can influence the equilibrium between soil test extractable and non-extractable forms of K.

Sulfur. The summary shows an increase in frequency of soils testing low in S, which is consistent with reports of increasing S deficiency in crops. Most scientists, however, do not consider S soil tests to be diagnostic without ancillary information, so agronomic interpretation strictly from the tests themselves is limited.

Zinc. With 37% of samples testing less than 1 ppm Zn, and 16% less than 0.5 ppm Zn, many soils in NA should be responsive to Zn fertilization.

Chloride. The Northern Great Plains has a high frequency of soils low in Cl^-.

pH. Soil pH changes, as in the past, were minor with a NA median of 6.4, compared to 6.3 in 2010.

We in North America rely heavily on soil testing to assess soil fertility and guide future nutrient management decisions. This summary demonstrates the extreme variability of fertility levels and that they do indeed change over time. Producers who have soils that have not been sampled recently would have much to gain by getting into the regular practice of soil sampling. The increase in sample volume with the 2010 summary is a positive sign that more farmers and advisers are taking advantage of this valuable tool.

More detailed information, including soil test frequency distributions for states and provinces for 2010, 2005, and 2001, will soon be available in the publication *Soil Test Levels in North America, 2010* and the accompanying CD, available for purchase from IPNI. Check the article beginning on page 6 inside this issue for more data, figures, and interpretation of the summary results. Visit the website at: >http://info.ipni.net/soiltestsummary<.

Paul E. Fixen
IPNI Senior Vice President
and Director of Research

BETTER CROPS
WITH PLANT FOOD
International Plant Nutrition Institute
3500 Parkway Lane, Suite 550
Norcross, Georgia 30092-2806
www.ipni.net