BETTER CROPS
WITH PLANT FOOD

A Publication of the International Plant Nutrition Institute (IPNI)
2009 Number 4

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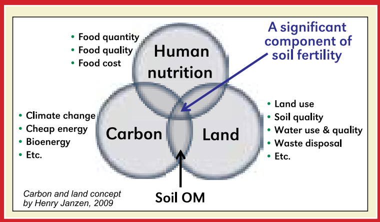
Does Fertilizer N "Burn Up" Soil Organic Matter?

Improving Crop Productivity and Nutrient Use Efficiency



Chloride Fertilization and Soil Testing

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2009 IPNI Scholar Award Winners

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BETTER CROPS
WITH PLANT FOOD

Vol. XCIII (93) 2009, No. 4

Our cover: Corn harvest.
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2009 Scholar Award Recipients Announced by IPNI

The 2009 winners of the Scholar Award sponsored by the International Plant Nutrition Institute (IPNI) have been selected. The awards of US$2,000 (two thousand dollars) are available to graduate students in sciences relevant to plant nutrition and management of crop nutrients.

"There were many highly qualified applicants this year from a wide array of universities and fields of study," said Dr. Terry L. Roberts, IPNI President. "The academic institutions these young people represent and their advisers and professors can be proud of their accomplishments. The selection committee adheres to rigorous criteria evaluating important aspects of each applicant's academic achievements."

In total, 14 (fourteen) graduate students were named to receive the IPNI Scholar Award in 2009, with the most widespread geographic distribution ever for the awards. They are listed below by region and university/institution.

North America: Daniel Edmonds, Oklahoma State University; Robert Burwell, Louisiana State University; Eduardo Kawakami, University of Arkansas; Melissa Wilson, University of Minnesota.

China: Hailong Liu, Chinese Academy of Agricultural Sciences; Juan Zou, Huazhong Agriculture University; Zhen-hua Zhang, Hunan Agricultural University; Yulin Liao, Hunan Agricultural University and Soil and Fertilizer Institute of Hunan Province.

India: Govindaraj Mahalingam, Tamil Nadu Agricultural University; Ramesh Thangavel, Indian Agricultural Research Institute, New Delhi.

Eastern Europe and Central Asia: Polina Kotyak, Yaroslavl State Agriculture Academy, Russia.

Latin America: Leandro Bortolon, Universidade Federal do Rio Grande do Sul, Brazil.

Southeast Asia: José Alvaro Cristancho Rodriguez, Universiti Putra Malaysia.

Australia: Preeti Roychand, La Trobe University, Melbourne.

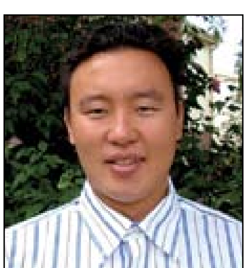
Funding for the Scholar Award program is provided through support of IPNI member companies, primary producers of nitrogen, phosphate, potash, and other fertilizers. Graduate students attending a degree-granting institution located in any country with an IPNI program region are eligible. Students in the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

Daniel Edmonds

Mr. Daniel Edmonds is pursuing a Ph.D. degree in Soil Science at Oklahoma State University, with a dissertation titled "By-Plant Nitrogen Fertilization in Maize (*Zea mays* L.)." Combining height, distance, and DFP-INSEY(days-from-planting in-season estimated yield) have recently provided the tools needed to generate improved prediction of yield potential. Past studies with by-plant N fertilization methods have not simultaneously combined Normalized Difference Vegetation Index (NDVI), plant height, and distance to and from adjoining plants within one algorithm. The goal of his research is to deliver a by-plant N fertilization strategy that results in increased corn grain yields as well as increased N use efficiency. In addition to his research, Mr. Edmonds has worked in a wide range of other responsibilities and traveled extensively as a leader in sensor-based N management training.

Robert Burwell

Mr. Robert Burwell is working towards his masters (M.S.) degree in the Department of Plant, Environmental, and Soil Sciences at Louisiana State University. His thesis title is "Nutrient and Sediment Losses from Surface Runoff during Bermudagrass (*Cynodon dactylon*) Establishment on a Levee Embankment." Because mature vegetation has been shown to greatly reduce surface runoff occurrence and severity after levee construction in areas such as New Orleans, fertilizers are used to accelerate vegetative establishment. Slow release fertilizers and other practices are being studied for potential in reducing nutrient run-off losses in these conditions. Mr. Burwell's research is intended to develop best management plans to reduce nutrient and sediment loading during vegetative establishment on new levees.



Eduardo Kawakami

Mr. Eduardo Kawakami is completing his Ph.D. degree in Crop Physiology at the University of Arkansas, with a dissertation titled "Physiological and Yield Responses of Cotton (*Gossypium* spp.) to Urea with NBPT and DCD under Different Stress Conditions." The outcome of his research should help cotton farmers perfect N fertilization practices, with higher yields and minimum impact on the environment. His project involves evaluation of urea with and without the urease inhibitor NBPT on cotton growth and yield under different temperature and salinity conditions. A native of Brazil, Mr. Kawakami has a strong interest in best management practices, using balanced nutrition with improved cultivars of crops for sustainable agricultural systems.

(continued on next page)

Melissa Wilson

Ms. Melissa Wilson began her Ph.D. program in Water Resources Science in 2008 at the University of Minnesota. Her dissertation is titled "Factors Affecting the Successful Establishment of Aerially-Seeded Winter Rye." Her project is intended to improve understanding of barriers to establishment of winter rye cover crops in southern Minnesota. In a corn-soybean rotation, aerially seeding winter rye into standing crops in the early fall can reduced nitrate leaching loss during the off-season. Part of the study Ms. Wilson is conducting involves local stakeholders who are interested in developing winter cover crop programs.

Hailong Liu

Mr. Hailong Liu registered his Ph.D. degree study with the Chinese Academy of Agricultural Sciences in 2007. He was awarded a scholarship under the State Scholarship Fund in China and is conducting his research in Canada at the Greenhouse and Processing Crops Research Centre of Agriculture and Agri-Food Canada in Harrow, Ontario (2009-2011). His dissertation title is "Testing and Validation of a Crop and Soil Model to Simulate Crop Growth, Soil Carbon, and Nitrogen Dynamics Using Field Experimental Data in Canada and China." When the study is complete, his findings will allow the Decision Support System for Agrotechnology Transfer (DSSAT) model to be successfully used in plant nutrition and soil fertility management to ensure sustained development of crop production and scientific use of fertilizer in both China and Canada.

Yulin Liao

Mr. Yulin Liao is completing his Ph.D. degree program in Plant Nutrition at Hunan Agricultural University and conducting his research at the Soil and Fertilizer Institute of Hunan Province in China. His dissertation is titled "Effect of Long-term Application of Potassium on Rice Yield and Potassium Supplying Capacity in Paddy Soil in Middle Reaches Regions of the Yantze River." Mr. Liao has studied the effects of returning rice straw to the soil as part of a long-term balanced fertilization program. This practice can significantly increase soil organic matter as well as sustainability of the production system.

Juan Zou

Ms. Juan Zou is completing her Ph.D. degree in Plant Nutrition at Huazhong Agriculture University in Wuhan, Hubei Province, China. Her dissertation title is "Study of the Fertilization Effect, Soil Nutrients Abundant and Deficient Indexes and Fertilizer Recommendations for Winter Rapeseed along Yantze River Valley." There has been little research on rapeseed response to fertilization in China. Ms. Zou's project will help establish soil nutrient indices and lead to reasonable fertilizer recommendations.

Zhen-hua Zhang

Mr. Zhen-hua Zhang is continuing is a Ph.D. degree program in Crop Physiology with Hunan Agricultural University in China and conducting his research at the International Rice Research Institute in the Philippines. His dissertation title is "Potassium, Calcium, and Manganese Requirements of Rice under Salt Stress and Roles of Plant Hormones in Mediating Responses to Nutrient Deficiency in Saline Soils." Salinity is a major obstacle for agricultural production in many parts of the world. Mr. Zhang's study will provide better understanding of phytohormones and concentrations of key nutrients to increase the salt tolerance of rice.

Govindaraj Mahalingam

Mr. Govindaraj Mahalingam began his Ph.D. program in 2007 in Plant Breeding and Genetics at Tamil Nadu Agricultural University, Coimbatore, India. His dissertation title is "Genetics of Grain Iron and Zinc Content in Pearl Millet" and the study is focused on assessing and evaluating the genetic efficiency of pearl millet genotypes for the accumulation of iron and zinc content in grain. Enhancement of mineral nutrition in grain is essential to eradicate human mineral malnutrition, especially in resource-poor populations of developing nations. For the future, development of genotypes having higher nutrient use efficiency, especially for iron and zinc, is important to enable production on many soils. This research can significantly increase the mineral content of grain and enable other agronomic advantages in crop plants.

Ramesh Thangavel

Mr. Ramesh Thangavel began his Ph.D. program in 2008 in Soil Science and Agricultural Chemistry at the Indian Agricultural Research Institute (IARI) in New Delhi. His dissertation title is "Stocks and Quality of Soil Organic Matter under Different Land Use Systems in East Khasi Hills of Meghalaya." Objectives of his project include quantifying and qualifying soil organic matter stocks in different land use systems under slash and burn cultivation, and studying carbon stability mechanisms in Northeast India. For the future, this could lead to great reduction in soil erosion and much improved land use patterns.

Polina Kotyak

Ms. Polina Kotyak is completing an advanced degree (M.Sc. equivalent) program in General Farming at Yaroslavl State Agriculture Academy in Russia. Her thesis title is "Impact of Herbicides, Fertilizer, and Different Intensity of Cultivation Systems on Biological Properties of Sod-Podzol Gleyey Soil and Yield of Crops." Russia has large areas of gleyey soils, which are subject to temporary overwetting and pose many challenges related to tillage and crop production, including weed and pest control difficulties. Objectives of this study were to gain a better understanding of energy-efficient tillage and soil management and improvement practices. Results indicate advantages for a system of plowing every 4 years, with surface cultivation after harvest in the other 3 years, to incorporate straw and fertilizer into the soil. After defending her thesis, Ms. Kotyak plans to continue her studies toward a doctorate degree.

Leandro Bortolon

Mr. Leandro Bortolon is completing requirements for his Ph.D. degree in Soil Fertility and Nutrient Management at Universidade Federal do Rio Grande do Sul in Brazil. His thesis title is "Phosphorus Dynamics in Soils under No-Tillage Affected by Land Use and Their Relationship with Crop Yields." An important focus of his research is to evaluate best management practices for phosphorus in no-till systems of southern Brazil, based on nutrient use efficiency and economic and environmental aspects. Extensive field work was conducted over the last 4 years to address P use efficiency for protecting soil and water quality and long-term practices for P as a finite resource. In addition, Mr. Bortolon works in a wide range of other responsibilities, mainly in soil testing efficiency with focus on multi-element extraction and determination methods.

José Cristancho Rodriguez

Mr. José Alvaro Cristancho Rodriguez is pursuing a Ph.D. degree in Soil Fertility and Plant Nutrition at Universiti Putra Malaysia. His dissertation title is "Soil Acidity Effects on Oil Palm Nutrition: Aluminum Effect and Amelioration of Aluminum Toxicity in Highly Acidic Soils and Its Effect on Growth, Nutrient Uptake, and Physiology of Hybrids and Clonal Oil Palm (*Elaeis guineensis*, Jacq.) Seedlings." Results have indicated benefits of ground magnesium limestone in neutralizing soil acidity for oil palm seedling growth. However, response varies with soil type and oil palm planting materials. Many oil palm producing regions have highly acidic soil conditions which can benefit by improved management. For the future, Mr. Cristancho Rodriguez hopes to further study relationships between oil palm nutrition and plant diseases.

Preeti Roychand

Ms. Preeti Roychand began her program in 2009 for a Ph.D. degree in Soils at La Trobe University in Melbourne, Australia. Her dissertation title is "Carbon Sequestration and Protection in Soil." The objectives of her project are to determine the physico-chemical processes which protect organic matter within the soil based on carbon saturation level, exact size of pores within the aggregates where organic matter remains protected, type of minerals responsible for protection of organic matter, and carbon pool size of each fraction. From her previous work as a research fellow at Punjab Agricultural University, she has about 20 research publications. She has received a special appreciation award from the International Potash Institute and Plant Nutrient Sulphur award from The Sulphur Institute.

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. More information is available from IPNI staff, from individual universities, or from the IPNI website: >www.ipni.net/awards<.

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

Does Fertilizer N "Burn Up" Soil Organic Matter?

By J.H. Grove, E.M. Pena-Yewtukhiw, M. Diaz-Zorita, and R.L. Blevins

This long-term Kentucky study evaluated the impact of tillage and N rates on crop yield and soil organic matter (SOM). After 29 years of continuous corn with a winter cereal cover crop, the combination of no-till cropping and fertilizer N use resulted in SOM levels similar to those in adjacent grass sod. There was no evidence that fertilizer N caused SOM loss.

Historically, soil scientists thought soil organic carbon (SOC) and N to be inextricably, and positively, coupled. Soil science textbooks note losses of SOM and "associated nutrients", including N, P, and S when discussing soil productivity degradation. Though much research effort is now directed towards soil quality and C sequestration, most recent research reports on these topics are not accompanied by information regarding changes in the status of the other organic-bound soil nutrients.

Current emphasis on soil C storage means that understanding soil/crop management practices contributing to SOM gain/loss is important. Again, textbooks generally teach that crop productivity is increased when a needed nutrient (or any other limiting factor) is provided. Plant growth provides the residual C that eventually becomes SOC. Because, next to water, fertilizer N is the largest driver of cereal crop growth, it is generally believed that needed plant nutrition contributes positively to SOM. In contrast, Khan et al. (2007), using historical and new data from the long-term Morrow plots at the University of Illinois, reported that their "research findings implicate fertilizer N in promoting the decomposition of crop residues and soil organic matter…" This challenges the established view.

Close reading of the paper by Khan et al. (2007) indicates that the changes in SOM that were observed result from a number of co-incident and confounding practices/processes. The Morrow Plots were converted from tall-grass prairie in 1876, tile-drained in 1904, subjected to complete crop residue removal until 1955 (all plots) or 1967 (some plots), and chisel plowed rather than moldboard plowed after 1997. Soybean replaced oats in one of two rotations in 1967. Selected plots were converted from co-applications of organic C and other nutrients (as manure) to inorganic fertilizer nutrient sources in 1955 (some plots) and 1967 (some more plots). Such confounding begs sampling appropriate temporal and spatial 'controls'.

Our objective was to examine the agronomic and soil evidence needed to test the hypothesis that long use of fertilizer N has resulted in a depletion of SOC. We determined profile SOC levels resulting from: 1) the conversion of an established sod to continuous corn production; 2) the continuous use of no-tillage (NT) or moldboard plow (MP) soil tillage management; and 3) the continuous application of zero, adequate, or excessive quantities of fertilizer N.

Methodology

This field trial was started in 1970 on the University of Kentucky research farm near Lexington. The site was a bluegrass (*Poa pratensis* L.) pasture for the previous 50 years. The soil is a well-drained Maury silt loam (fine, mixed semi-active, mesic Typic Paleudalfs). The experiment is continuously summer cropped to corn (*Zea mays* L.) for grain, followed by a winter annual cereal cover crop. Moldboard plowing, to a depth of 8 to 10 in., is done in the third or fourth week of April, about 1 to 2 weeks before planting corn. The NT crop is seeded through prior corn and cover crop residues using a cutting coulter-double disk opener planter equipped with row cleaners. The fertilizer N source, ammonium nitrate, is surface broadcast within 1 week of planting. Corn is harvested in late September or early October, and a NT drill is used to plant the winter cereal cover crop through the combine-shredded residues left over the surface of the entire experiment.

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; ave = average.

Experimental area: post tillage and pre-plant.

Experimental area: vigorous mid-vegetative growth.

Table 1. Average corn grain yields: First 15, last 15, and all 39 years.

Tillage system	Fertilizer N rate, lb/A	First 15 years (1970-1984)	Last 15 years (1994-2008)	All 39 years (1970-2008)
		------ Corn grain yield, bu/A ------		
Moldboard plow	0	86	44	60
	75	120	101	106
	150	123	116	116
	300	128	123	122
No tillage	0	71	52	61
	75	116	112	110
	150	126	133	126
	300	128	130	126

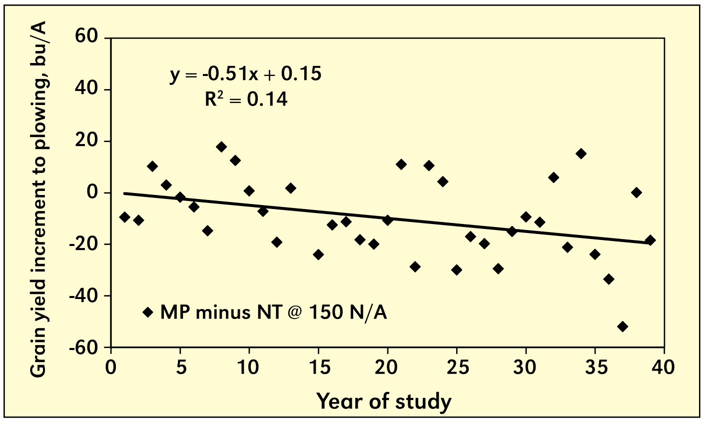


Figure 1. Grain yield increment to moldboard plowing at 150 lb N/A over the course of the study.

The experiment contains four replications of two tillage treatments, NT and MP, and four fertilizer N rates (0, 75, 150, and 300 lb N/A/year). Tillage and N rate treatments have been maintained on the same plots for the duration of the experiment. Three intact soil cores were taken, to a depth of 40 in., from the 0, 150, and 300 lb N/A/year plots and from the unfertilized surrounding grass sod at each of the four corners of the trial. Cores were divided into 4 in. depth increments, composited, and sub-sampled for gravimetric moisture content and subsequent calculation of soil bulk density. The remainder was air-dried and crushed. Air-dried samples were used to determine SOC by dry combustion.

Observations

Corn growth differences due to fertilizer N are often dramatic (bottom photo, previous page), as are growth differences in the winter cover crop (top photo, previous page), though the latter are rarely measured. Averaged over 39 years of study, there is little difference in corn yield response to N for the two different tillage systems, but that response has changed over time **(Table 1)**. The first 15 years, NT corn was more N responsive, but MP corn has become more N responsive the last 15 years. Generally, 150 lb N/A has been the nearly optimal N rate, in both tillage systems **(Table 1)**. The annual yield response to plowing, at 150 lb N/A, was positive in 12 of 39 years, but is declining with time, at 0.5 bu/A/year **(Figure 1)**. As suggested by the decline in unfertilized corn yields in **Table 1**, the agronomic efficiency for fertilizer N (lb corn/lb N) has increased with time, in both tillage systems **(Figure 2)**. Initially, the annual fertilizer N yield response was greater with NT, but that for MP rose 25% faster, and has become similar.

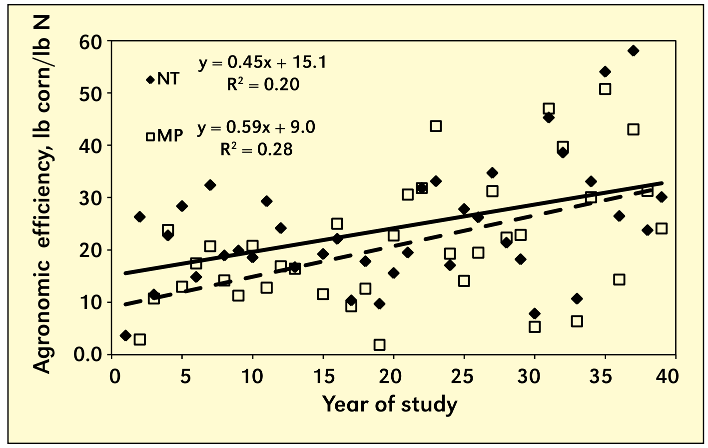


Figure 2. Corn agronomic efficiency (lb corn/lb N) for the first 150 lb N/A, over the time course of the study.

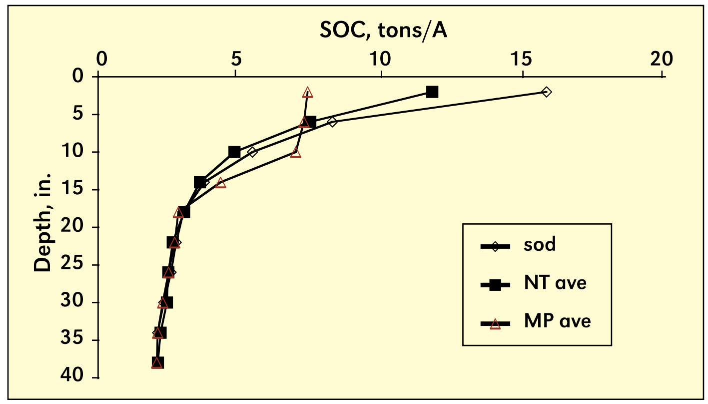


Figure 3. The impact of tillage systems (averaged across fertilizer N rates) on the distribution of SOC within the soil profile.

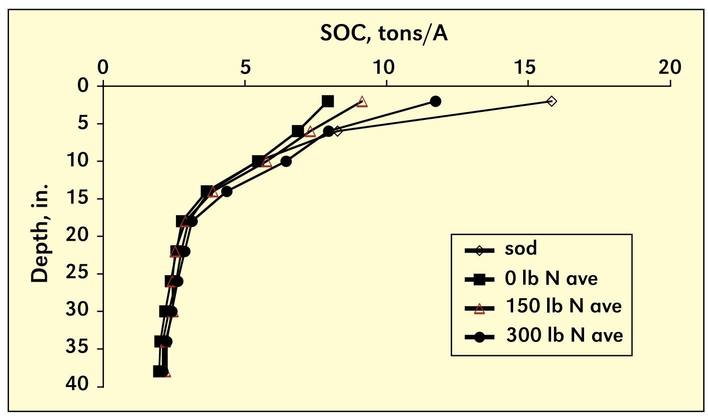


Figure 4. The impact of fertilizer N rates (averaged across tillage systems) on the distribution of SOC within the soil profile.

Figures 3 and 4 illustrate how the long-term treatments have caused differences in the distribution of C within the sampled soil profiles. The impact of tillage on SOC, relative to the surrounding sod, is limited to the upper 16 in. of the profile **(Figure 3)**. Continuous no-till corn production has resulted in a SOC distribution similar to that of the surrounding sod. Moldboard plow tillage causes a more uniform SOC distribution

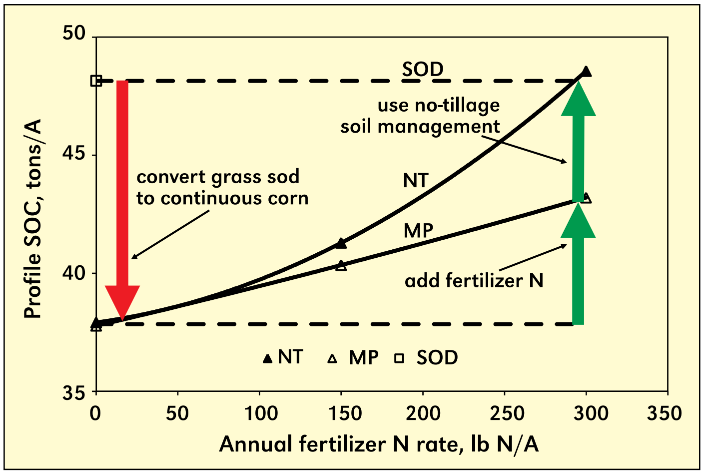


Figure 5. The impact of fertilizer N on total profile SOC levels found after 39 years of cropping to continuous corn with a winter cereal cover crop.

in the upper 12 in. of soil. Fertilizer N rate influenced profile SOC to a depth of 20 to 24 in., probably because of greater root growth with N fertilization **(Figure 4)**. The surface 4 to 8 in. of soil exhibited the greatest SOC response to fertilizer N rate. The unfertilized sod exhibited the greatest SOC, primarily because of the large amount (16 tons/A) found in the surface 4 in. of soil.

Interpretation/Conclusion

Figure 5 summarizes our findings. Profile SOC was as low as 38 tons/A, where corn has been grown without N fertilization, and regardless of tillage system. Profile SOC was as high as 48 tons/A, under the unfertilized grass sod and also where NT corn was grown with an agronomically excessive annual N fertilization rate of 300 lb N/A/year. Without N fertilizer, conversion of grass sod to continuous corn, with a winter cereal cover crop, has resulted in about 20% less SOC. At 150 lb N/A/year, the corn soils contain about 15% less SOC than the sod. Plow tillage has an increasing impact on SOC with greater fertilizer N rate, resulting in 10% less SOC at 300 lb N/A/year.

The agronomic evidence indicates that fertilizer N is needed for adequate yield and that the need for supplemental N nutrition has become greater with time and tillage. The greater need for added N is due to reduced soil N release from the SOM reservoir, itself diminished by both time and tillage.

There was no evidence that fertilizer N caused SOM loss. With NT and a winter cereal cover crop, 150 lb N/A/year appears to sustain corn yield, but it appears that more fertilizer N will be needed to sustain MP corn yield. Tillage-caused losses of SOM are outpacing N derived gains, at 150 lb N/A/year. The loss of SOC was more associated with agroecosystem change, than with tillage. The gain/maintenance of SOC was most associated with N fertilization, which presumably increased crop and winter cover crop dry matter formation, and with no-tillage, which conserves that carbon-laden material.

Well-informed soil management should cause, as much as is practical, SOM to be maintained/replaced. Soil management science should acknowledge, rather than confuse/confound, the roles of different practices, acting over different time frames. The oxidative practices (drainage, tillage, and fallow), the reductive practices (photosynthesis, immobilization, and denitrification), and the mass transfer practices (additions of compost, manure, etc.; removal of grain, stover, etc.) all contribute to the SOM we have today.

On this soil, crop productivity and C sequestration are intimately linked agroecosystem services – services fostered by management practices appropriate to this soil – no-tillage and fertilizer N application. BC

Dr. Grove (e-mail: jgrove@uky.edu) and Dr. Blevins are Associate Professor and Professor Emeritus, respectively, Department of Plant and Soil Sciences, University of Kentucky. Dr. Pena-Yewtukhiw is Assistant Professor, Division of Plant and Soil Sciences, West Virginia University. Dr. Diaz-Zorita is Adjunct Researcher, National Council of Science and Technologies (CONICET) and Faculty of Agronomy, University of Buenos Aires, Argentina.

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10th International Conference on Precision Agriculture Set for July 18-21 in Denver

The 10th International Conference on Precision Agriculture (ICPA) is set for July 18-21, 2010, in Denver, Colorado. Dr. Rajiv Khosla of Colorado State University will serve as Conference Chairperson for the event. Dr. Harold Reetz of IPNI/FAR serves on the Organizing Committee, along with Dr. Dwayne Westfall of Colorado State University and Mr. Quentin Rund of PAQ Interactive.

The ICPA is oriented primarily to research progress, and facilitates interactions among scientists, producers, technology company representatives, equipment manufacturers, input dealers, agronomic consultants, software developers, educators, government personnel, and policymakers. Find out more at the ICPA website: **www.icpaonline.org**. BC

Ammonia Emissions from Agricultural Operations: Fertilizer

By Robert Mikkelsen

Nitrogen fertilizer is an essential component on most farms. Although urea-based fertilizers are the most common global N source, they are susceptible to loss as ammonia (NH_3) gas when left on the soil surface. Ammonia losses from fertilizer can represent a significant economic loss for farmers and can have a negative effect on air quality, ecosystem productivity, and human health. The major factors controlling NH_3 losses from fertilizers are reviewed in this article.

Getting the most value from all nutrient inputs is necessary to maximize efficiency. Selecting the right source of nutrient in a particular cropping situation requires a consideration of economic, environmental, and social objectives. One of the objectives is to keep all nutrient losses to a minimum. Some N fertilizers can be subject to volatile losses to the atmosphere. Regulatory agencies are increasing their awareness of the role of N gases in the atmosphere and their potentially undesirable consequences.

A previous article (*Better Crops* No. 1, 2009) discussed the loss of NH_3 from animal production facilities. While livestock operations are the largest contributor to NH_3 emissions in North America, losses from N fertilizer also contribute significantly to total emissions. Where significant NH_3 loss occurs following fertilization, it is possible that the crops may be under-fertilized due to this unintentional N loss.

A variety of soil chemical properties interact with environmental conditions at the site of the fertilizer application to determine the extent of NH_3 loss **(Figure 1)**. This article reviews some of the major factors that contribute to NH_3 loss from N fertilizer.

Nitrogen Source All fertilizers containing ammonium (NH_4^+) are theoretically subject to volatile loss. However, properties of each specific fertilizer and its reactions after contacting the soil can result in large differences in N loss. The potential for NH_3 volatilization is largely governed by the alkalinity (pH) of the zone surrounding the fertilizer particle or droplet. Many NH_4^+-containing fertilizers such as ammonium nitrate or ammonium sulfate initially form a slightly acidic solution when they dissolve in the soil (pH between 4.5 and 5.5). In most circumstances, these N forms do not have significant NH_3 loss.

When urea is applied to soil, it reacts chemically with water (hydrolysis) and the urease enzyme to produce ammonium carbonate – an unstable compound that can quickly decompose to release NH_3 gas. Ammonium carbonate is commonly used for smelling salts because it readily releases NH_3. Whether applied alone or in a solution, urea undergoes these reactions when applied to soil:

Hydrolysis Reactions of Urea

$(NH_2)_2CO + 2H_2O \rightarrow (NH_4)_2CO_3$
Urea Ammonium Carbonate

$(NH_4)_2CO_3 + 2H^+ \rightarrow 2NH_4^+ + CO_2 + H_2O$
(reaction consumes acidity, raising pH)

$NH_4^+ + OH^- \rightarrow NH_3 + H_2O \quad (pK_a = 9.3)$

Abbreviations and notes: N = nitrogen; CEC = cation exchange capacity.

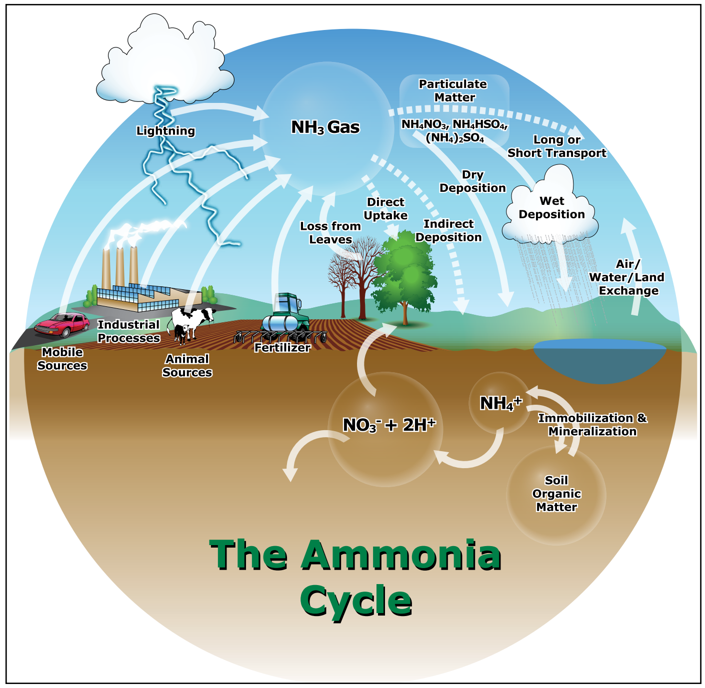


Figure 1. Ammonia emission, transport, and deposition from major sources.

Field factors favoring NH_3 volatilization losses from surface-applied urea:
– No rain or irrigation after application (or light mist)
– Crop residue on the soil surface
– High temperatures
– High soil pH
– Low clay and organic matter (low CEC)
– Initially moist soil followed by drying

When broadcast on the soil surface, both liquid or dry urea or urea-containing sources can be susceptible to NH_3 loss. There are some reports where liquid urea sources are more susceptible to NH_3 loss than dry fertilizers and other reports that indicate opposite results. These apparent contradictions are likely due to the specific field conditions influencing the movement of urea into the soil, where it becomes protected from volatilization loss.

Placement Fertilizers are most commonly broadcast on the soil surface, applied as a surface band, or applied as a subsurface band. Leaving urea-containing fertilizer on the soil surface without incorporation (by tillage or rainfall/irrigation) increases the risk of NH_3 volatilization in the days following application. Since urea moves freely with water until it

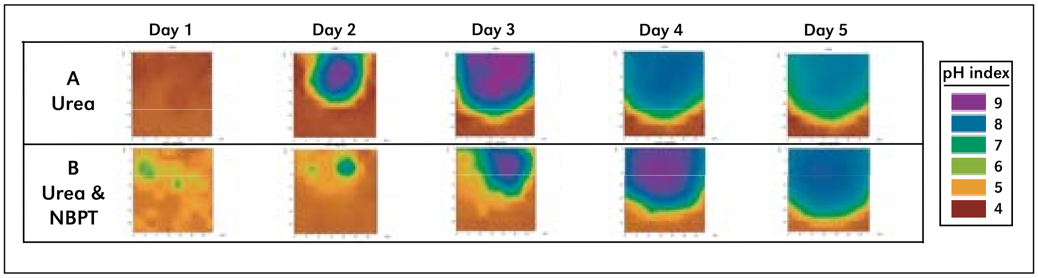


Figure 2. The effect of (A) urea alone or (B) urea with NBPT urease inhibitor on soil pH over 4 days following application. The soil pH increased from 4.6 to over 9 surrounding the granule within 1 day following fertilization with untreated urea. Each image is approximately 1 in. (27 mm) square of soil. Data from Stephan Blossfeld and Agrotain International.

Estimates of NH_3 volatilization from urea fertilizer vary widely due to the many conditions where this popular fertilizer is used. Published reports of volatile N loss from surface-applied urea range from near zero to close to 100% in extreme conditions. When urea or urea-containing N sources remain on the soil surface for a prolonged period of time, typical losses between 10 and 40% may be expected. In your environment, NH_3 losses may be greater or less than this. Always use appropriate fertilizer management practices such as right source, rate, timing, and placement to keep NH_3 losses to a minimum.

hydrolyzes to NH_4^+, apply urea immediately prior to rainfall or irrigation if possible to allow it to move with water beneath the soil surface.

Broadcasting urea onto the canopy of crops (such as a pasture or a forest) may result in significant NH_3 losses. Surface banding the added N in concentrated zones can reduce NH_3 losses compared with spraying the urea N across the field in this situation. In forested soils, NH_3 loss following urea application can be greater from bare soil than from soil with a complete forest floor due to the pH buffering capacity of the humus layer.

Ammonia loss is a concern in no-till crop production where N is commonly applied to the soil surface. No-till practices may result in a layer of crop residue that can increase the risk of NH_3 losses, compared with bare soil. Volatile losses can be significant in these circumstances since i) urease activity is generally high in crop residues, ii) crop residues form a barrier which can prevent urea from reaching the mineral soil, and iii) a vegetative mulch may keep the soil more moist – all of which can increase NH_3 loss.

When subsurface application is not feasible, application of urea in a surface band is superior to broadcast application for minimizing NH_3 loss. This occurs as the capacity of the soil to hydrolyze urea is exceeded within this localized band, giving additional time for downward movement of urea into the soil where it is protected from NH_3 loss. Therefore, the most effective way to conserve urea is to get urea into the soil and not on top of the soil for a prolonged period.

Soil pH The conversion of NH_4^+ to NH_3 gas is governed by pH. A variety of reactions occur following N fertilization that will influence the microsite pH. During urea hydrolysis, the pH surrounding the granule initially rises (> pH 8) as ammonium bicarbonate is formed **(Figure 2)**. It is during this period of urea hydrolysis and increased pH that NH_3 loss is most likely. Many environmental factors can influence the rate of urea hydrolysis, such as the urea concentration, urease enzyme activity, temperature, moisture, and the presence of crop residues. During the warm growing season, it is common for most of applied urea to be hydrolyzed within a week.

Ammonia loss occurs even from acid soils since urea hydrolysis causes the pH to rise at the site of the fertilizer placement and transform NH_3 to a gas. The example in **Figure 2** shows the soil pH rising from 4.6 to over 9 following urea application. A greater pH buffering capacity of soil is generally related to less volatile NH_3 loss, and soils that are high in clay and organic matter tend to have greater pH buffering.

The bacterial process of nitrification subsequently oxidizes NH_4^+ to NO_3^-, releasing acidity in the process and dropping the soil pH below the initial soil pH before urea was added. As NH_4^+ is oxidized to NO_3^-, the risk of volatile loss decreases. However, once in the NO_3^- form, other pathways of N loss become more likely (such as denitrification or leaching).

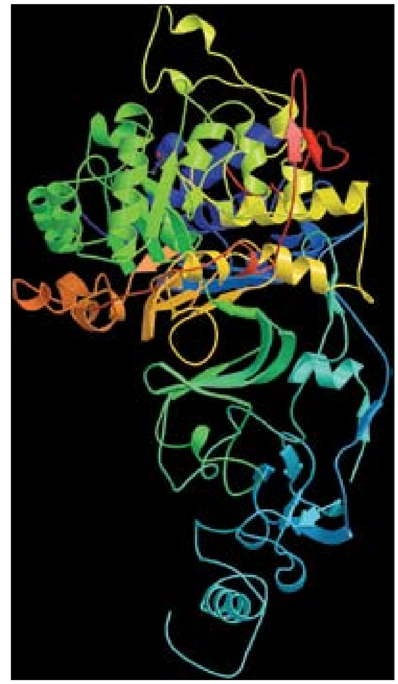


Figure 3. Chemical model of the urease enzyme responsible for hydrolysis.

Source: Protein Data Bank (PDB 1E9Z) Supramolecular Assembly and Acid Resistance of Helicobacter Pylori Urease.
Ha, N.-C., Oh, S.-T., Sung, J.Y., Cha, K.-A., Hyung Lee, M., and Oh, B.-H. 2001. Nat. Struct. Biol. 8: 480.

Moisture is the major mechanism for moving surface-applied urea into the soil.

An extensive set of field studies was conducted in the Central Valley of California to estimate large-scale NH_3 losses from applied fertilizer. Total NH_3 losses ranged from 0.9 lb to 6.2 lb N/A (averaging 3.2% of applied N) from a variety of cropping situations using NH_4-based fertilizers. The researchers suggested a state-wide average NH_3 emission factor for all N fertilizer applications to be 2.4% of added N fertilizer.

Soil Moisture When urea or NH_4^+-based fertilizers are added to dry soil, the dissolution is slow and biological and chemical reactions do not rapidly occur. Urea hydrolysis also becomes very slow and approaches zero when the soil is quite dry. Higher NH_3 losses are expected when the relative humidity of the air is greater than the critical humidity of urea. However, moisture is the major mechanism for moving surface-applied urea into the soil and essential in making the nutrients available for plant uptake from the soil solution.

Soil Properties Soil cation exchange sites are a major mechanism for removing NH_4^+ from the soil solution. Soils with a greater CEC generally have the ability to retain more NH_4^+ and reduce volatile losses. Since sandy soils generally have lower CEC and buffer capacity, the magnitude of soil pH changes and NH_3 losses can be significant.

Windspeed Losses of NH_3 from surface-applied urea generally increase in windy conditions. Since windy conditions and drying soils are often related, both of these factors tend to aggravate the potential for volatile NH_3 loss.

Temperature Ammonia losses generally increase with rising temperatures due to effects on both chemical and biochemical reactions. Higher temperatures speed the hydrolysis of urea, resulting in a higher soil pH and greater NH_3 concentrations. Higher temperatures also shift the equilibrium to favor NH_3 gas over the NH_4^+ form. Therefore, NH_3 loss may be slightly higher during the warmer part of the year, and daily spikes may occur during hot times of the day. However, since soil drying also favors NH_3 loss, this factor often interacts with temperature and windspeed.

Urea Hydrolysis Urease enzymes are produced by almost all plants, animals, and microorganisms. Its absence is almost never a limiting factor for converting urea into NH_4^+ **(Figure 3)**.

Flooded Soils Volatile losses of NH_3 from irrigation and flood water may be large. A high concentration of NH_3, high water pH, warm temperature, and elevated wind speed all contribute to the likelihood of loss. When broadcast into floodwater, urea is more susceptible to volatilization than a fertilizer such as ammonium sulfate since the pH is likely to rise as urea is hydrolyzed to ammonium carbonate. Photosynthesis by plants and algae in water will also increase the pH of the water when CO_2 is depleted during the daytime, causing pH to rise as high as 9. During nighttime, CO_2 is released during respiration and the water pH decreases again. Placement of urea below the soil surface largely eliminates NH_3 volatile loss.

When anhydrous or aqua NH_3 is added to irrigation water, significant volatile losses can occur as water is applied to the field through sprinklers or irrigation furrows. Less NH_3 loss occurs when using UAN (a 1:1 mixture of urea and ammonium nitrate) since only half of the fertilizer is present as urea.

Photo courtesy of Agrium Advanced Technology

Coatings on controlled release fertilizer can effectively reduce the amount of soluble urea exposed to the soil environment and minimize NH_3 loss.

Fertilizer Modifications Fertilizer must sometimes be applied when conditions are not optimal. Several approaches have been used to reduce NH_3 losses from fertilizer in these circumstances, including urease inhibitors, fertilizer coatings, acidification, or the addition of calcium salts.

A number of compounds have been screened to identify an effective way to block or delay urea hydrolysis. The product most commonly used, especially in North America, is N-(n-Butyl)-thiophosphoric triamide (NBPT) sold under the commercial name of Agrotain. This product is combined with urea to inhibit the urease enzyme for a period of several days to two weeks depending on the application rate **(Figure 2)**. NBPT is especially beneficial for gaining time for rainfall or irrigation to move surface-applied urea into the soil where it is not susceptible to volatile loss.

A variety of materials have been successfully used as coatings for controlled-release fertilizers to limit the solubility of urea. Coatings can effectively reduce the amount of soluble urea exposed to the soil environment at any one time and significantly reduce N losses in many circumstances.

Urea can be reacted with a variety of strong acids to maintain a low pH in the vicinity of the fertilizer granule or solution. Commercial products of urea-sulfuric acid and urea-phosphoric acid are available for specialized purposes.

The addition of soluble calcium salts (such as $CaCl_2$) to urea has been shown to reduce NH_3 loss from both acid and calcareous soils by depressing pH as well as reacting with the carbonate molecules formed during urea hydrolysis. Urea fertilizer containing boron and copper compounds to partially inhibit urease activity and a coating of acidic monoammonium phosphate is also commercially available to help minimize NH_3 loss.

Ammonia volatilization from applied N fertilizers represents an economic loss of a valuable resource and a potential concern for air quality. With careful management and awareness of the conditions conducive for loss, N fertilizer can be properly managed to minimize the potential for volatile loss. BC

Dr. Mikkelsen is IPNI Western North America Regional Director, based at Merced, California; e-mail: rmikkelsen@ipni.net.

Concepts for Facilitating the Improvement of Crop Productivity and Nutrient Use Efficiency

By Paul E. Fixen

The global character of the demand for agricultural products and many of the most critical environmental issues creates a tight linkage between improving productivity and minimizing environmental impact. Merging these two objectives into one goal is likely the only strategic approach that will allow either objective to be accomplished. Sustainably meeting this challenging goal will require close cooperation and understanding among disciplines, across geographies, and between public and private sectors. Three concepts are offered that may facilitate this interaction.

- **The 4R Nutrient Stewardship Framework: Application of the right nutrient source, at the right rate, right time, and right place is a concept that when seen within a framework connecting practices to on-farm objectives and sustainability goals, along with critical performance indicators, can help keep individuals working on "parts" cognizant of the "whole".**
- **Mainstreaming of Simulation Models: Models recently developed can help identify unrealized yield potential and better manage the growing uncertainty of weather and climate.**
- **Global Data Networks: More extensive exploitation of electronic technology that facilitates global data collection, sharing, analysis, and use could expedite the acquisition and application of agronomic and plant nutrition knowledge.**

The Critical Role of Soil Fertility in Food and the Environment

Three underlying factors that encompass many of the major issues humankind will be facing for the next several decades are human nutrition, carbon (C), and land **(Figure 1)**. Two of these factors, C and land, were recently discussed in an inspiring paper presented by Dr. Henry Janzen at the International Symposium on Soil Organic Matter Dynamics (Janzen, 2009). Carbon issues include climate change, cheap energy, and bioenergy. Land issues include land use, soil quality, water use and quality, and waste disposal. Dr. Janzen astutely pointed out that soil organic matter is the common ground between these two factors. The addition of human nutrition as a third factor brings into the picture the issues of food quantity, food quality, and food cost. Of critical importance in the discussion of nutrient management is that a significant component of the common ground of all three of these huge factors is soil fertility and how the management of plant nutrients affects our food supply, our land, and the C cycle.

Agricultural Productivity and Nutrient Use Efficiency (NUE) as One

Sustainable development is widely recognized as consisting of economic, social, and environmental elements. Sustainable nutrient management must support cropping systems that contribute to all three of these elements. Considering the increasing societal demand for food, fiber, and fuel, intense global financial stress, and growing concerns over impacts on water and air quality, simultaneous improvement of productivity and NUE is an essential goal for global agriculture. Striving to improve NUE without also improving productivity simply increases pressure to produce more on other lands that may be less suited to efficient production. Likewise, the squandering of resources to maximize productivity resulting in increased adverse environmental impact puts more pressure on other lands to reduce environmental impact while meeting productivity needs.

Abbreviations and notes: N = nitrogen; BMPs = best management practices.

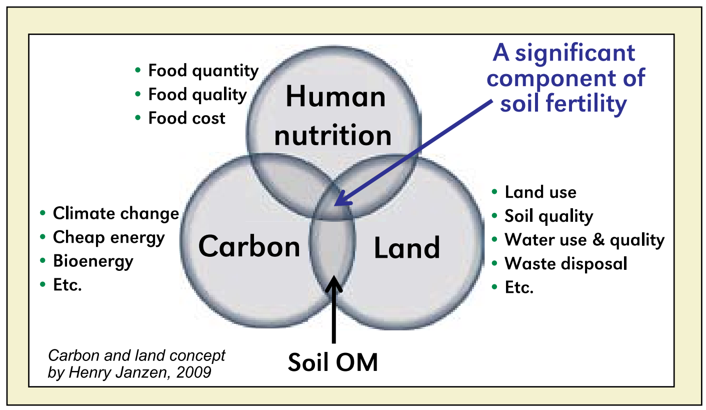


Figure 1. Underlying factors for the challenges of the coming decades.

Simultaneous pursuit of higher productivity and NUE requires caution in how NUE is being measured. Methods of NUE determination and their interpretation were recently reviewed by Dobermann (2007). He also summarized the current status of NUE for major crops around the world, pointing out that

Photo by José Espinosa

Soil fertility greatly impacts the productivity of our land and the carbon cycle.

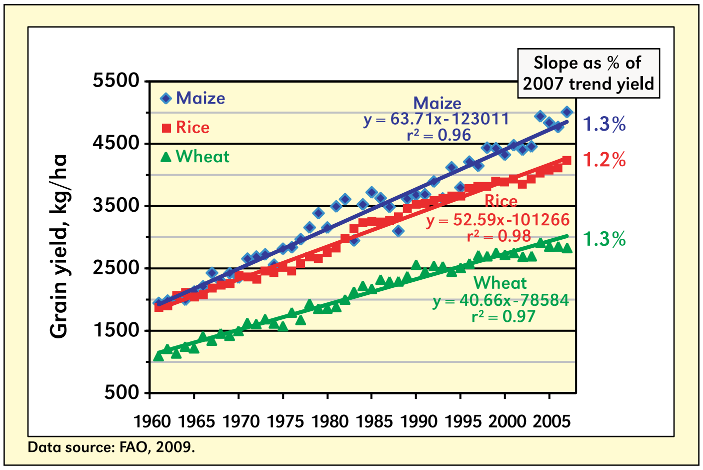


Figure 2. Global cereal yield trends.

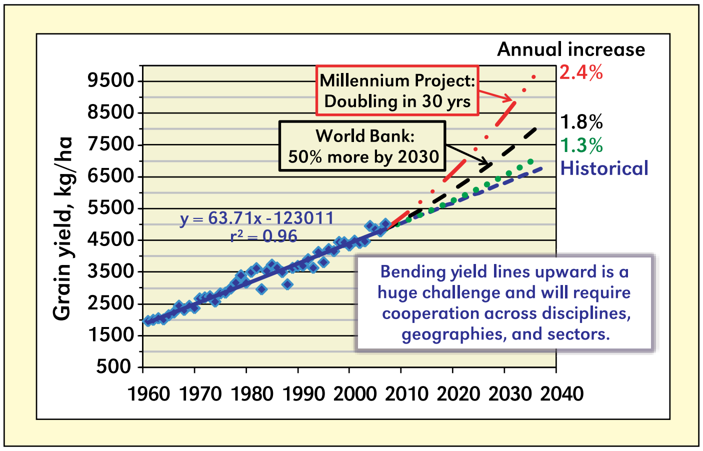


Figure 3. Future demand projections applied to maize yields.

single-year average recovery efficiency for N in farmer fields is often less than 40%, but that the best managers operated at much higher efficiencies. Dobermann used a 6-year study in Nebraska on irrigated continuous maize managed at recommended and intensive levels of plant density and fertilization to illustrate how NUE expressions can be easily misinterpreted. In this study, comparing a higher yielding, intensively managed system to the recommended system for the region, the partial factor productivity (PFP or grain produced per unit of N applied) index indicated that the intensive system was considerably less N efficient than the recommended system. Because fertilizer N contributed to the buildup of soil organic matter in the intensive system, when the change in soil N was taken into account, the two systems had nearly the same system level N efficiency. Dobermann pointed out that over time, this increased soil N supply should eventually reduce the need for fertilizer N, resulting in an increase in PFP. Such effects are particularly noteworthy when striving to increase productivity with more intensive methods where new practices are being implemented that differ from the history for the research plot area or farm field. If cultural practice changes are such that soil organic matter is no longer in steady state, temporary net nutrient immobilization or mineralization can impact apparent NUE.

Some have estimated that the world will need twice as much food within 30 years (Glenn et al., 2008). That is equivalent to maintaining a proportional annual rate of increase of over 2.4% over that 30-year period. Others predict a 50% increase

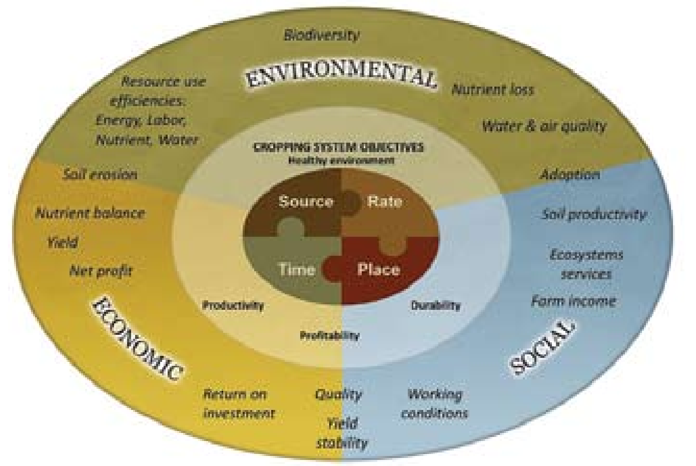


Figure 4. The 4R nutrient stewardship framework (after Bruulsema et. al., 2008).

in food demand by 2030 which translates into a 1.8% annual increase (Evans, 2009). Sustainably meeting such demand is a huge challenge and will require close cooperation and understanding among disciplines, across geographies, and between public and private sectors. The magnitude of the challenge is appreciated when such a proportional rate of increase is compared to historical cereal yield trends which have been linear for nearly half a century with slopes equal to only 1.2 to 1.3% of 2007 yields **(Figure 2** and **Figure 3)**. Three concepts are offered here that may facilitate cooperation among the groups needed to accomplish the required productivity and efficiency improvements.

The 4R Nutrient Stewardship Framework

For plant nutrition science to work well across disciplines, between public and private sectors, and across geographies, a common framework for viewing goals, practices, and performance is likely helpful. The seeds for such a framework were planted more than 20 years ago by Thorup and Stewart (1988) when they wrote: "This means using the right kind of fertilizer, in the right amount, in the right place, at the right time." **Figure 4** is a schematic representation of the 4R nutrient stewardship framework based on the concepts described by Thorup and Stewart (Bruulsema et al., 2008). At its core are the 4Rs – application of the right nutrient source at the right rate, right time, and right place. Best management practices are the in-field manifestation of these 4Rs.

The 4Rs are shown within a cropping system circle because they integrate with agronomic BMPs selected to achieve crop management objectives. Those farm-level crop management objectives contribute toward the larger economic, social and environmental goals of sustainable development. Furthermore, the 4Rs cannot truly be realized if problems exist with other aspects of the cropping system. Darst and Murphy (1994) wrote about the lessons of the Dust Bowl in the USA in the 1930s coupled with a multitude of research studies showing the merits of proper fertilization and other new production technology, catalyzing the fusing of conservation and agronomic BMPs. Science and experience clearly show that the impact of a fertilizer BMP on crop yield, crop quality, profitability and nutrient loss to water or air is greatly influenced by other agronomic (plant population, cultivar, tillage, pest management, etc.) and conservation practices (terracing, strip cropping, residue

Table 1. A comparison of long-term average maize yields in an intensive management study to local average farmer yields (experimental data from Adviento-Borbe et al., 2007).

Average of 2000-2005	Continuous maize	Maize/ soybean
Lancaster County irrigated farmer average, t/ha	10.6	
University recommended treatment, t/ha	14.0	14.7
Intensive high yield management treatment, t/ha	15.0	15.6

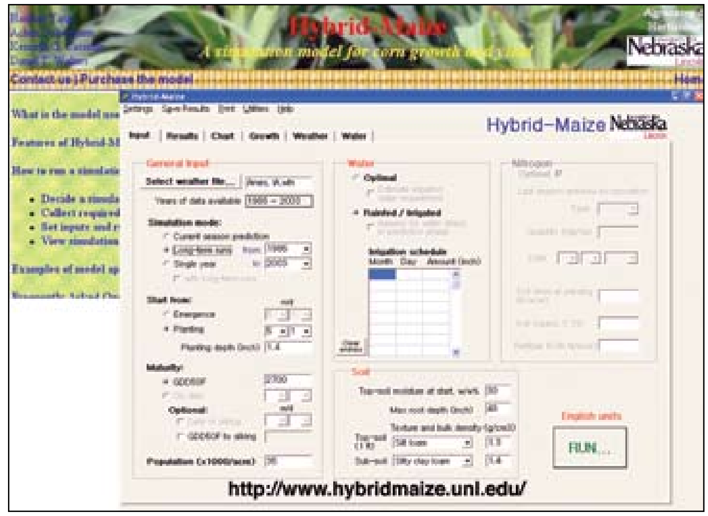
management, riparian buffers, shelter belts, etc.). Practices defined with sufficient specificity to be useful in making on-farm fertilizer use decisions, often are "best" practices only when in the appropriate context of other agronomic and conservation BMPs. A fertilizer BMP can be totally ineffective if the cropping system in which it is employed has other serious inadequacies.

Around the outer circle of the 4R framework are examples of performance indicators. A balanced complement of these indicators can reflect the influence of nutrient BMPs on accomplishment of the goals of sustainable development. The framework shows clearly that system sustainability involves more than yield and NUE, though these are critical indicators. Stakeholder input into performance indicators is an essential part of the process.

Mainstreaming of Simulation Models

Defining the gap between current and potential yields is a useful step towards maximizing productivity and efficiency. FAO recently published a set of such estimates for six maize-producing countries (FAO, 2008). Their evaluation showed a yield gap varying from 4 or 5 t/ha in Mexico or India to zero for the USA. However, such existing general estimates should not be taken too literally relative to specific locations. For example, if one compares the Nebraska irrigated maize yields for the intensively managed treatments discussed earlier to the county average farmer yields for the same time-period, a difference of 4 to 5 t/ha is observed **(Table 1)**, suggesting that a yield gap exists in at least some areas of the USA as well.

Crop simulation models can be useful tools for site-specific estimation of yield gaps. Significant progress has been made in user-friendly crop simulation models with the potential to assist with gap analysis and crop and nutrient management. One example is Hybrid Maize, developed by the University of Nebraska (Yang et al., 2006). Nutrient management functionality for the model is under development. Crop and nutrient management is complex in part because critical processes in plants and in soils are highly dependent on weather. In practice, managers have two options, either base decisions on climatic probabilities or on in-season, near real time information. Simulation models can assist with either approach. Climate change adds another dimension to the utility of weather/climate driven models. A recent report by the National Research Council (2009) stated that the end of climate stationarity requires organized, data-based decision support for climate-sensitive decisions. It would seem that crop and soil management would fall into that category of climate-sensitive decisions. Implications of climate change on plant nutrition were recently reviewed by Brouder and Volenec (2008). A thorough review of crop yield gaps with a focus on wheat, rice, and maize, including use of simulation models, was recently published by Lobell et al.(2009).



Hybrid-Maize is an example of a crop simulation model for site-specific estimation of the gap between current and potential corn yield.

Global Data Networks

In its recent synthesis report, the International Assessment of Agricultural Knowledge, Science and Technology for Development stated that the main challenge for agricultural knowledge, science and technology (AKST) is to increase the productivity of agriculture in a sustainable manner (IAASTD, 2009). It proposed that one of six high priority natural resource management (NRM) options for action is to "Develop networks of AKST practitioners (farmer organizations, NGOs, government, private sector) to facilitate long-term NRM to enhance benefits from natural resources for the collective good. A second option was to "connect globalization and localization pathways that link locally generated NRM knowledge and innovations to public and private AKST."

In her plenary lecture at the 2008 annual meeting of the American Association for the Advancement of Science, Dr. Nina Fedoroff, Administrator of USAID, said that the only alternative to higher food prices and progressive deforestation is to use contemporary science, including molecular modification, to increase the productivity of the land we already farm and decrease its water demands (Fedoroff, 2008). She went on to say that our research universities and institutes, working together with the business sector and using contemporary electronic resources, have a unique opportunity to accelerate global collaboration.

Can current communication and data management technologies be put to better use in pursuing our productivity and NUE goals? The National Academy of Sciences (2009) now tells beginning scientists that researchers have a responsibility to devise ways to share their data in the best ways possible, mentioning repositories of astronomical images, protein sequences, archaeological data, cell lines, reagents, and transgenic animals as examples.

To address unmet communication needs of collaborating scientists, Purdue University researchers developed the Network for Computational Nanotechnology (NCN). An outcome of this network was nanoHUB (http://www.nanohub.org). This

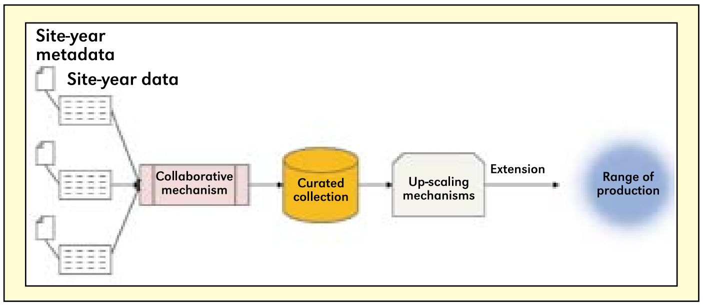


Figure 5. A conceptual model of the process of developing and testing field data across large geographic scales (Murrell, 2008).

on-line community of over 90,000 annual users provides web access to the tools scientists need to collaborate on modeling, research, and educational efforts in nanotechnology. Is there need for a "Nutrohub", a global plant nutrition research and education community? Such a community could have numerous groups, each with its own focus, but sharing communication and computing tools. Groups could develop integrated data management processes such as the one illustrated in **Figure 5**, developed for IPNI's Global Maize project (Murrell, 2008). BC

Dr. Fixen is IPNI Senior Vice President, Americas Group, and Director of Research. He is located at Brookings, South Dakota; e-mail: pfixen@ipni.net.

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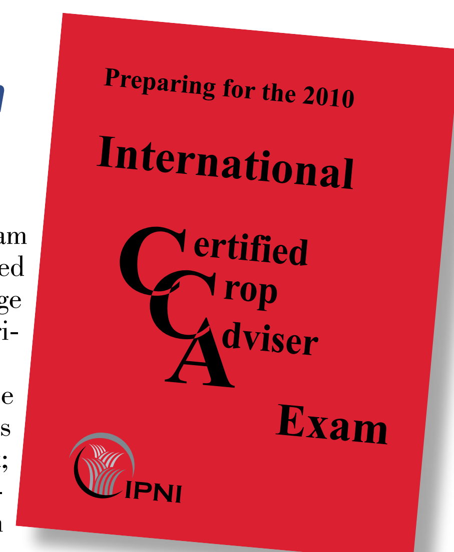
Preparing for the 2010 International Certified Crop Adviser Exam Study Guide Available from IPNI



Individuals preparing for the 2010 International Certified Crop Adviser ICCA exam will be interested to know that an updated edition of the popular study guide offered by the International Plant Nutrition Institute (IPNI) is now available. The 173-page training guide is organized and updated each year by Dr. John Gilmour, Professor Emeritus, University of Arkansas, and published by IPNI.

The ICCA exam is based on performance objectives considered as areas of expertise that a Certified Crop Adviser (CCA) should possess. The performance objectives areas are: Nutrient Management; Soil and Water Management; Integrated Pest Management; and Crop Management. The study guide presents subject information for each performance objective, supplemented by sample questions. The study guide includes an answer key for the sample questions.

The 2010 edition of the ICCA exam study guide (Item #50-1000) is available for purchase directly from IPNI. The price of US$50.00 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 URL: >www.ipni.net/ccamanual<. BC

Predicting Agronomic Boundaries of Future Fertilizer Needs in AgriStats

By Christian Witt, Julie Mae Pasuquin, and Gavin Sulewski

Predicting fertilizer consumption for a given crop and country is challenging. In this article, we explore an agronomic model based on yield gap analysis, fertilization for attainable yield, and area growth featuring case studies from Indonesia.

Predicting fertilizer requirements is of interest to both public and private sector players involved in fertilizer production, distribution, or market development activities. Key challenges in anticipating fertilizer use include limitations in available agricultural statistics on current fertilizer use by country and crop and uncertainties in quantifying the complex nature of factors affecting future nutrient needs. In this paper, we describe components of an agronomic model used in AgriStats, a database on agricultural statistics at the International Plant Nutrition Institute (IPNI), to generate realistic scenarios of fertilizer consumption.

The model is based on a robust yield gap analysis using estimates of actual, attainable, and potential yield. By estimating the fertilizer requirements necessary to overcome existing nutrient limitations of a crop in a specific region, scenarios of fertilizer use can be constructed for the three yield levels. We have purposely excluded economics in our analysis and focus on the inherent agronomic constraints and projected advances in knowledge and technological adoption. In the following, we describe the model in greater detail before presenting a case study from Indonesia on current and future fertilizer use in rice and oil palm.

Actual, Attainable, and Potential Yield

The conceptual framework for the identification of yield gaps is given in **Figure 1**. The yield potential (Yp) is the theoretical maximum yield of a crop in any given season

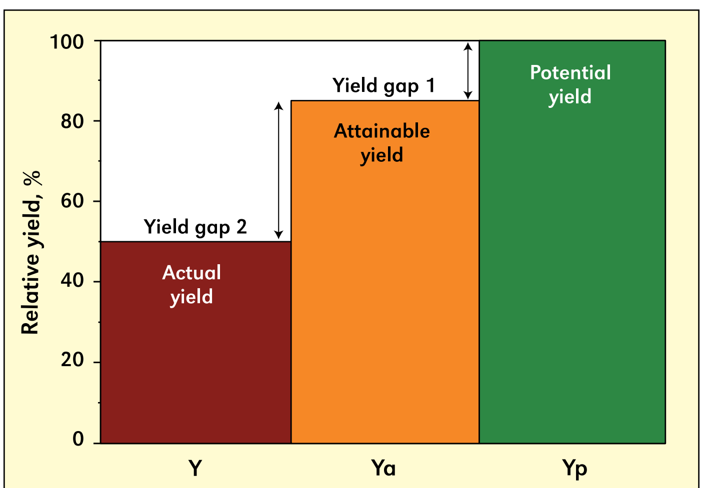


Figure 1. Conceptual framework for the identification of exploitable yield gaps.

Abbreviations: N = nitrogen; P = phosphorus; K = potassium; M t = million metric tons.

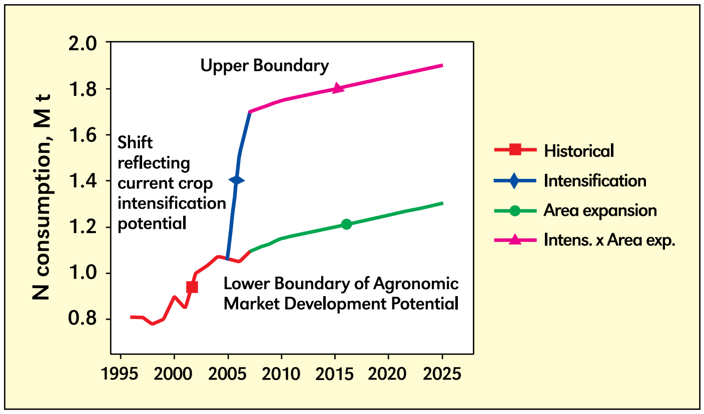


Figure 2. Idealized graph of agronomic market development scenarios.

determined solely by climate and germplasm. By definition, water and nutrients are not limiting yield and yield-reducing factors such as pests and diseases are absent. Yp is commonly estimated using plant growth models and would follow the year-to-year variation in climate.

The attainable yield (Ya) is defined as the yield achieved in farmers' fields with best management practices including water, pest, and general crop management where nutrients are not limiting. Soil constraints or water availability may limit Ya. The attainable yield varies – like the yield potential – from season to season and year to year depending on climate. A meaningful yield target is often closely associated with attainable yield. The maximum attainable yield in any given season could be close to the yield potential, if management is excellent and weather conditions are very favorable. Investments in knowledge or infrastructure (e.g. irrigation facilities) or soil improvement measures could substantially increase attainable yield. It is usually not economical to aim at fully reducing the difference in potential and attainable yield (Yield gap 1) because of the large amounts of inputs required and the high risk of crop failure and profit losses.

The actual yield (Y) in farmers' fields is often lower than the attainable yield due to constraints like poor crop and nutrient management practices that may also enhance pest and disease pressure. The difference between actual and attainable yield (Yield gap 2) is the realistically exploitable yield gap. New technologies and implementation of best management practices can significantly narrow this yield gap. Statistical services (e.g. FAO, USDA) usually provide historical estimates of actual yield for a given crop and country or region

Agronomic Boundaries of Fertilizer Use

In AgriStats, fertilizer use by country and crop is calculated using application rate (kg/ha), total cropped area (ha), and

Table 1. Actual and attainable rice and oil palm production and fertilizer use in Indonesia.

Parameter	Unit	Rice Actual	Rice Attainable	Oil-Palm Actual	Oil-Palm Attainable
Yield[1]	t/ha	4.7	5.7	16.8	25.0
Area	M ha	12.1	12.3	5.5	6.8
Production	M t	57.2	70.0	92.0	170.0
Fertilizer N	kg/ha	100	120	90	90
Fertilizer P_2O_5	kg/ha	25	30	45	55
Fertilizer K_2O	kg/ha	20	35	160	200
Area fertilized N	%	90	90	80	90
Area fertilized P	%	90	90	70	90
Area fertilized K	%	40	70	70	90

[1]Oil palm yield refers to fresh fruit bunches, assuming an oil extraction rate of 21%.
Data sources: current yield, area, and production for rice, FAO, 2007 (http://faostat.fao.org); current yield, area (assuming 80% of total 6.8 M ha under mature palms), and production for oil palm by IOPRI, 2008 (http://iopri.org); fertilizer rates and area fertilized, IPNI AgriStats (http://agristats.ipni.net).

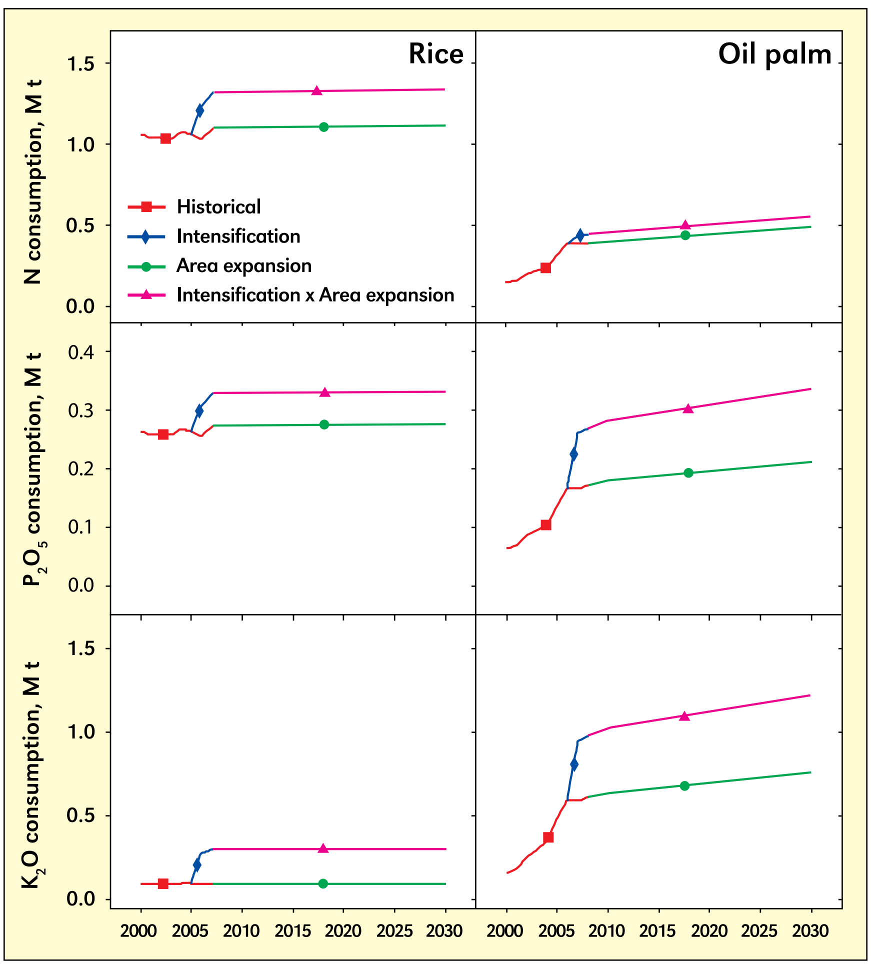


Figure 3. Projections of NPK consumption for rice (left) and oil palm (right) in Indonesia.

the percentage of cropped area that is fertilized. Agronomic boundaries of future fertilizer use are then modeled for any given crop and region based on historical/current consumption trends and realistic expectations of medium to long-term changes in these factors **(Figure 2)**.

- The historical consumption (red line) refers to historical fertilizer use based on estimates of actual yield and corresponding historical rates of fertilization, historical harvested area, and historical percentage of fertilized area.
- The intensification potential (blue line) is based on current harvested area and realistic estimates of changes in percentage of fertilized area and fertilizer use to reach the attainable yield. This scenario portrays the current market development potential.
- The area expansion model (green line) portrays future estimates of consumption based on current fertilization practices and realistic expectations for future harvested area.
- The intensification x area expansion model (purple line) depicts future estimates of consumption based on attainable improvements in fertilizer use and expected changes in harvested area.

The two latter projections of future fertilizer consumption delineate the most likely lower and upper boundaries of potential agronomic market development. It should be noted, however, that unfavorable economics (e.g. commodity prices), resource availability (e.g. fertilizer), or poor technology adoption limit the agronomic market development potential. The actual market development, therefore, is expected to take place between the portrayed boundaries of area expansion and intensification x area expansion.

Case Study – Fertilizer Consumption of Rice and Oil Palm in Indonesia

In the following, we explore the concept of fertilizer use scenarios for rice and oil palm, two of the most important agricultural crops in Indonesia. Most fertilizer in the country is consumed by these two crops. Among the Southeast Asian countries, Indonesia is the top producer of rice while Malaysia and Indonesia dominate the oil palm sector. The actual and attainable production characteristics and fertilizer use in rice and oil palm given in **Table 1** were used to develop fertilizer use scenarios depicted in **Figure 3**.

Production Characteristics and Fertilizer Use

Rice is characterized by moderate opportunities for yield increases, mainly because of limitations in attainable yield **(Table 1)**. A large area is currently cropped to rice, but the scope for further expansion of rice-growing areas is small and there is loss of agricultural land to urbanization, land conversion, and industrialization. Future fertilizer rates corresponding to the attainable yield for rice are projected to be slightly higher than actual rates **(Figure 3)**. Rice farmers in Indonesia generally apply adequate amounts of fertilizers, although overuse of fertilizer N is common in intensively cropped areas. Future fertilizer use assumes improved crop and nutrient management to reach the attainable yield. The proportion of cropped area fertilized with N and P

(continued on next page)

In Memoriam: Dr. Norman Borlaug, 1914-2009

The IPNI Board of Directors issued a brief statement honoring the legacy of Dr. Norman Borlaug, who passed away on September 12 in Dallas, Texas, at the age of 95.

The message of the IPNI Board of Directors states: *We join with millions of people around the world in expressing appreciation and admiration for the great achievements of Dr. Norman Borlaug. His dedication to science in agriculture is responsible for improving the lives of individuals around the world over the past 50 years and into the future. In an amazing journey from his Iowa farm roots to world recognition as a Nobel Peace Prize laureate, he never lost sight of the importance of global food security and the power of science through agriculture. Dr. Borlaug was considered by many as the father of the 'Green Revolution' as his early work in plant breeding led to great increases in harvests of cereal crops in Mexico, India, Pakistan, and other countries. His phenomenal success in breeding high-yielding varieties of wheat, rice, and other crops evolved into broader initiatives in training young agricultural scientists, educating audiences around the globe, and furthering important humanitarian causes. The International Plant Nutrition Institute extends its condolences to the Borlaug family and to his many friends and colleagues. While we are saddened by the loss of this innovative scientist and beloved leader, we believe his vision and accomplishments will serve as inspiration to future generations to continue the quest for world food security.*

Photo source: AgriLife

Dr. Borlaug in field plots.

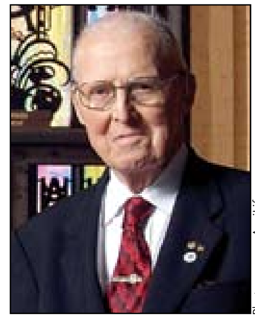


Photo source: AgriLife

Dr. Norman Borlaug

"Dr. Borlaug was one of those rare individuals who made the most of his fame and influence to champion the cause of applying science for humanitarian benefits," noted IPNI President Dr. Terry Roberts. "He recognized the role of fertilizer in producing the world's food and took every opportunity to remind policymakers and the public that fertilizer is a critical component of global food security."

In July 2007, Dr. Borlaug received the Congressional Gold Medal, the highest honor given by Congress.

A public memorial at Texas A&M University on October 6, 2009, celebrated the life and work of Dr. Borlaug. About 1,000 people attended the service. To learn more about his vision and legacy, visit the website of the Norman Borlaug Institute for International Agriculture: >http://borlaug.tamu.edu<. BC

Photo source: AgriLife

Bringing the Green revolution to Africa was one of Dr. Borlaug's goals.

AgriStats... *from page 17*

is likely to remain constant in the future, while area fertilized with K is expected to slightly increase as yields increase.

Oil palm production in Indonesia is projected to significantly increase because of both area expansion and opportunities for yield intensification. To meet the nutrient requirements at higher yield and considering lower soil fertility of available land for oil palm, fertilizer P and K use is expected to increase. Fertilizer N rates may remain the same assuming advancements in N management leading to greater efficiency.

Fertilizer Use Scenarios

Future fertilizer use in rice largely depends on farmers' ability to intensify production considering limitations in area expansion **(Figure 3)**. As a result, the upper and lower boundaries of future fertilizer use in rice do not show much change with time. In contrast, the expected increase in area under oil palm will likely result in an increase of fertilizer consumption (lower green boundary), while opportunities for yield intensification are associated with increased fertilizer use, particularly of P and K. Comparing the two crops, rice will remain to be the larger consumer of fertilizer N, while fertilizer P consumption in oil palm may reach the levels observed in rice depending on future yield intensification. Oil palm will continue to consume more fertilizer K than rice and this gap is likely to widen in the future.

Conclusions

Boundaries of future fertilizer use scenarios for a given crop and region can be estimated using current knowledge on yield gaps and realistic expectations on crop intensification and area expansion. It is understood that any economic constraints of the day will combine with agronomic constraints to modify the likelihood of achieving the full extent of the shifts in crop intensification that are indicated.

By employing the concepts of yield gap analysis and future fertilizer use scenarios within AgriStats, we have begun to build a global database with analytical tools able to construct comparisons across countries and crops. The overall goal is to systematically improve our understanding of attainable yield and crop production in a given country or region, providing further guidance on knowledge gaps to be addressed through field research and crop modeling. BC

Dr. Witt is Director, IPNI Southeast Asia Program, e-mail: cwitt@ipni.net. Mrs. Pasuquin is Agronomist, IPNI Southeast Asia Program, e-mail: jmpasuquin@ipni.net. Mr. Sulewski is Agronomic and Technical Support Specialist, IPNI, e-mail: gsulewski@ipni.net.

Note to Readers

AgriStats is currently a private service available to members of IPNI. Inquiries may be sent to gsulewski@ipni.net.

2009 IPNI Science Award Goes to Dr. J.K. Ladha of India

The International Plant Nutrition Institute (IPNI) has named Dr. J.K. Ladha as the winner of the 2009 IPNI Science Award. Dr. Ladha is a senior soil scientist, Coordinator of the Rice-Wheat Consortium in Asia, and representative of the International Rice Research Institute (IRRI) in India. He receives a special plaque plus a monetary award of US$5,000 (five thousand dollars).

"Dr. Ladha is a truly outstanding scientist and most deserving of this recognition due to the scope and breadth of his research, training, and extension activities," said Dr. Terry L. Roberts, President of IPNI. "He has made immense contributions to international agriculture through his activities in several Asian countries, on problems across national and regional boundaries."

Born in Gwalior, India, Dr. Ladha earned his Ph.D. in Botany from Banaras Hindu University in 1976. Earlier, he earned his B.Sc. in Biological Sciences in 1971 and his M.Sc. in Botany in 1975 at Jiwaji University in India. He has devoted nearly 30 years of his career to working in the area of integrated resource management with strong emphasis on soil fertility and nutrient management for achieving increased crop yields. Dr. Ladha has been an associate in the Agricultural Experiment Station at the University of California-Davis since 2002. He was a "Frosty" Hill Fellow at Cornell University (July 2007 to June 2008) and an adjunct professor of Soil Science at the University of the Philippines (1990 to 2004).

Dr. Ladha's work, in collaboration with many national partners, takes a holistic, systems approach covering various components of agronomic, soil, and water management. He emphasizes farmer-participatory approaches for developing innovative resource-use-efficient alternatives of tillage/crop establishment and fertilizer management strategies. Through his work, several resource-conserving technologies, notably laser-leveling, minimum tillage, direct-seeded rice, and need-based management of nutrients have been adopted on a large scale, helping resource-poor farmers. Recently, Dr. Ladha was one of the key innovators and continues as a leader of the Cereal Systems Initiative for South Asia (CSISA) project that seeks to improve food security for millions of people.

Dr. J.K. Ladha

Implementation of research findings has been a major part of Dr. Ladha's effort throughout his career. He has published extensively in leading peer-reviewed journals and edited several books. He has authored or co-authored 183 research articles in international research journals, 60 articles in proceedings and other books, and has edited or co-edited 11 books.

For his many achievements, Dr. Ladha has been honored with numerous awards, including election as Fellow of the American Society of Agronomy, Fellow of the Soil Science Society of America, and Fellow of the American Association for the Advancement of Science (AAAS).

The IPNI Science Award is intended to recognize outstanding achievements in research, extension, or education, with a focus on efficient and effective management of plant nutrients and their positive interaction in fully integrated crop production that enhances yield potential and crop quality. Private or public sector agronomists, soil scientists, and crop scientists from all countries are eligible for nomination. The previous recipients of the IPNI Science Award were Dr. John Ryan of ICARDA in 2008 and Dr. M.S. Aulakh of India in 2007. BC

International Zinc Association Joins IPNI

The International Zinc Association (IZA) has joined the International Plant Nutrition Institute (IPNI) as an Associate Member.

"Our members welcome the International Zinc Association and anticipate positive benefits as our programs develop," stated IPNI President Dr. Terry L. Roberts. IPNI was launched January 1, 2007. Its mission is to develop and promote scientific information about the responsible management of plant nutrition for the benefit of the human family.

Founded in 1990, IZA is a non-profit organization based in Brusssels, Belgium, and representing the global zinc industry by promoting zinc's essentiality in present and potential product applications, human health, and crop nutrition, and by highlighting zinc's contribution to sustainable development.

Membership in IPNI is composed primarily of companies that are basic producers of one or more of the major plant nutrients (nitrogen, phosphate, potash, and sulfur) for agricultural purposes. The organization seeks to provide a coordinated scientific foundation for fertilizer nutrient use and to scientifically address associated environmental issues.

"Zinc is essential for the health of humans and crops. However, zinc deficiency affects nearly one-third of the world's population and leads to deaths of over 800,000 people annually, including 450,000 children," said Stephen R. Wilkinson, Executive Director of IZA. "Increasing the use of zinc in fertilizers will help address this global problem by improving the nutritional status of crops while at the same time improving crop health and productivity." BC

Chloride Fertilization and Soil Testing – Update for Major Crops in Kansas

By David Mengel, Ray Lamond, Vic Martin, Stu Duncan, David Whitney, and Barney Gordon

Chloride (Cl^-) is the ion form of chlorine (Cl). It is an essential, but sometimes overlooked, nutrient in crop production. Years of work have shown that wheat and other crops can show substantial response to Cl^- application. This article discusses Cl^- nutrition and summarizes Kansas research results for major crops from the 1990s through 2006.

Although crop response to Cl^- application was suspected as early as the mid-1800s, Cl was first identified as an essential plant nutrient for growth and development in 1954 (Broyer et al., 1954). While Cl is classified as a micronutrient, the quantities of Cl^- taken up and present in the plant are comparable to many macronutrients. Concentrations of Cl^- in corn earleaf and wheat flagleaf at flowering are commonly found to range from 0.25 to 1%.

Plants take up Cl as the Cl^- ion from the soil solution, and the primary form of Cl in plants is Cl^-. Like nitrate (NO_3^-), Cl^- acts as a counter-ion for the transport and uptake of essential cations such as calcium (Ca^{2+}), potassium (K^+), magnesium (Mg^{2+}), and ammonium (NH_4^+). Chloride also plays important roles in enzyme activation (Broyer et al., 1954; Grant et al., 2003) and osmotic regulation (Kafkafi and Xu, 2002).

Perhaps one of the most important roles of Cl in plant growth is in the suppression of plant disease. Suppression of disease through Cl fertilization has been reported in many crops including corn, millet, wheat, and barley (Heckman, 2006). In Kansas, the suppression of leaf rust in wheat and stalk rots in sorghum are important.

In the Great Plains, the most commonly observed visual symptoms from Cl^- deficiency are seen on wheat. The deficiency symptoms appear as leaf spotting and are referred to as physiological leaf spot. Visible Cl deficiency symptoms have not been defined for most agronomic crops, including corn and sorghum, though yield responses have been obtained.

Most of the Cl in soils is present in the soil solution as Cl^-, and arrives from rainfall, marine aerosols, volcanic emissions, irrigation water, and fertilizers (Havlin et al., 2005). Most references cite deposition values from precipitation of 10 to 35 lb Cl^-/A per year, with higher values in coastal areas. However, recent reports from the U.S. Atmospheric Deposition Program show much lower values, ranging from 0.5 to 1 kg/ha (0.45 to 0.9 lb/A) across much of the Great Plains and >10 kg/ha (9 lb/A) in coastal areas. Substantial amounts of Cl can be found in irrigation water, often enough to meet crop needs (Mikkelsen, 2005). In areas that have low levels of K, Cl is typically added as muriate of potash (KCl) fertilizer, thus increasing Cl^- concentration in the soil (Engel et al., 1997; Lamond and Leikam, 2002).

Comparing wheat leaves from plot which received Cl^- (left) and untreated plot (right).

Bear (1929), in discussing K fertilizers, noted that KCl fertilizer secured better yields than sulfate of potash in areas of heavy rainfall that are far from the seashore. He later explained that Cl is generally deficient in "interior regions" where rainfall causes runoff and underground drainage.

Two excellent reviews on Cl^- in plants and soils are: Chapter 9, "Chlorine", by Dr. Joseph Heckman in *The Handbook of Plant Nutrition*, 2007 and "Crop Responses to Chloride" by Dr. Paul Fixen in *Advances in Agronomy*, volume 50, 1993.

Chloride Fertilization Research in Kansas

The earliest Cl^- field research results found for Kansas

Cimmaron variety wheat at Sandyland Experiment Field, Kansas, showed deficiency symptoms when no Cl^- was applied (left). With 24 lb Cl^-/A, leaf spotting was eliminated (above).

Abbreviations and notes: ppm = parts per million.

Table 1. Response of wheat to Cl^- fertilization in Kansas (derived from 34 experiments conducted from 1990-2006).

Cl^- applied, lb/A	Grain yield, bu/A	Leaf Cl^- at boot, %
0	48.4 b	0.29 c
10	51.7 a	0.38 b
20	52.5 a	0.43 a
LSD 0.05	1.3	0.03
n	34	30

Table 2. Response of dryland grain sorghum to applied Cl^- fertilizer in Kansas (derived from 20 site-years of data from 1996-2006).

Cl^- applied, lb/A	Grain yield, bu/A	Leaf Cl^- at boot, %
0	98.5 b	0.10 c
20	108.2 a	0.24 b
40	109.9 a	0.33 a
LSD 0.05	2.4	0.05
n	20	11

was from studies conducted in the early 1980s. Much of this work was sparked by reports of effects of Cl^- on plant disease. Bonczkowski (1989) and co-workers conducted a series of studies in Northeast Kansas comparing the use of KCl to fungicides on suppression of wheat rust. Work was also conducted at several locations, primarily with wheat, focused on nutrient response. Early results suggested that the greatest potential for response would be in dryland production in areas with no history of potash fertilization.

The following is a summary of Kansas Cl^- work conducted from 1990 to 2006. More details on the majority of these studies can be found in the Kansas Fertilizer Research Reports, published annually and available on-line at the K-State Research and Extension website: >www.ksre.ksu.edu/library<.

Wheat. In the period from 1990 to 2006, 39 field experiments were conducted, primarily in the eastern half of the state, looking at the response of hard red winter wheat to Cl^- fertilization. Nearly all these experiments were conducted under dryland conditions, in areas of high native soil K levels with no history of potash application. Various treatments were compared in these studies, with a focus on Cl^- application rate, Cl^- source, and time and/or method of application. Of the 39 studies, 23 showed a statistically significant response to Cl^- fertilization when analyzed individually.

The results from 34 of those experiments, all of which included common treatments of Cl^- fertilizer rates of 0, 10, and 20 lb/A applied as KCl broadcast in the spring, were combined and analyzed using each location as a replication and the treatment means at that location as individual observations. In each of these studies, non-K sources were included, allowing the separation of K response from Cl^- response. The results are summarized in **Table 1**.

A significant wheat yield response to Cl^- fertilization was found in the combined analysis of these studies. The addition of 10 lb of Cl^- increased wheat yield 3.3 bu/A across all sites, and no additional response to the 20 lb/A Cl^- rate was seen. Chloride fertilization increased the Cl^- content of the top leaves

Table 3. Response of dryland corn to applied Cl^- fertilizer in Kansas (derived from 11 studies conducted from 1990-2006).

Cl^- applied, lb/A	Grain yield, bu/A	Leaf Cl^- at tassel, %
0	104.4 b	0.17 c
20	108.9 a	0.27 b
40	111.6 a	0.36 a
LSD 0.05	3.4	0.05
n	11	11

at boot, with an increase in leaf Cl^- seen as rates increased.

Of the individual experiments, 21 used four rates of Cl^-: 0, 10, 20, and 30 lb/A. Again, a significant response in grain yield was seen with the first increment of Cl^- applied, with no additional response to higher rates.

A number of different materials were used as Cl^- sources in these studies, with comparisons of Cl^- fertilizers included at most sites. The most commonly used materials were KCl and sodium chloride (NaCl), with ammonium chloride (NH_4Cl), magnesium chloride ($MgCl_2$), and calcium chloride ($CaCl_2$) also used. While slight differences were observed in leaf Cl^- content between sources, no differences were observed between sources in yield response.

Sorghum. During the period of 1996 through 2006, 23 field trials were conducted examining the response of grain sorghum to applied Cl^- fertilizers. Of the 23 sites, 19 showed a significant yield response to Cl^- fertilization. Using the same process, a combined analysis was made of 20 site-years of data, looking at the response of sorghum to 0, 20, or 40 lb/A Cl^- applied broadcast pre-plant or pre-emerge as KCl or NH_4Cl **(Table 2)**.

As with wheat, a statistically significant yield response was seen to the first rate of Cl^- when data were combined across locations. In this case, the lowest rate was 20 lb/A Cl^-, with no additional response to the higher rate. Leaf Cl^- level went up with increased level of fertilization. Source comparisons were made in many of these studies, with no difference in effectiveness seen between KCl, NaCl, $CaCl_2$, and NH_4Cl.

Corn. Less work has been done examining the response of corn to Cl^- in Kansas, in part due to the large portion of the corn crop under irrigation (most of irrigation water in the state contains significant amounts of Cl^-) or in areas naturally low in soil K with a history of KCl applications. Eleven studies were conducted on dryland corn in the south central, north central, and north east portions of Kansas between 1996 and 2001. Only six of the 11 sites gave a significant yield response to Cl^- fertilization. The results from the 11 trials were combined and reported in **Table 3**. As with sorghum and wheat, a significant yield response was obtained to the first 20 lb/A of added Cl^-, with no additional response to additional Cl^-. Corn earleaf Cl^- levels increased with increasing rates of Cl^-. Some source comparisons were made with corn, and no differences were seen between sources tested. The number of source comparisons was too low to do a combined analysis.

Bromegrass. Chloride fertilization on bromegrass was also recently studied. A total of 10 experiments were conducted in 2004-2006. As with wheat, corn, and sorghum, increasing rates of Cl^- fertilizer increased the concentration of Cl^- in

Table 4. Soil test Cl^- interpretations and fertilizer recommendations for Kansas.

Category	Soil Cl^- in a 0 to 24 in. sample, lb/A	Soil Cl^- in a 0 to 24 in. sample, ppm	Cl^- recommended,[1] lb/A
Low	<30	<4	20
Medium	30-45	4-6	10
High	>45	>6	0

[1]Recommendations for corn, sorghum, and wheat only.

the plant tissue. However, no increases in forage yield were obtained at any of the sites. No recommendations for Cl^- fertilization of bromegrass are made in Kansas.

Soil and Plant Testing for Chloride

Based on this body of work, routine Cl^- soil tests and Cl^- fertilizer recommendations for wheat, sorghum, and corn have been offered by the Kansas State Soil Testing Lab since the mid-1990s. Plant analysis is also offered for research or diagnostic purposes. As with nitrate and sulfate, Cl^- soil testing is recommended using a 0 to 24 in. "profile" sample.

The interpretation of the Cl^- test and corresponding fertilizer recommendations for corn, sorghum, and wheat are given in **Table 4**. Chloride fertilizer is recommended for these crops at soil tests below 6 ppm, or 45 lb soil Cl^- in the 24 in. sample depth.

Summary

Chloride fertilization based on soil testing is gradually becoming an established practice in dryland wheat, sorghum, and corn production. More field testing is needed, particularly in western Kansas, to determine the breadth of the Cl^- deficient area, and to improve soil test correlations and calibrations. However, based on current data, the probability of a response to Cl^- in dryland wheat and sorghum production in central Kansas is high. BC

Dr. Mengel (e-mail: dmengel@ksu.edu) is Professor of Agronomy, Dr. Lamond (deceased) was Professor of Agronomy, Dr. Martin is Associate Professor, Dr. Duncan is Northeast Area Agronomist, Dr. Whitney is Professor Emeritus, and Dr. Gordon is Professor, all with the Department of Agronomy, Kansas State University, Manhattan, KS 66554.

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17. Signature and Title of Editor, Publisher, Business Manager, or Owner: Editor Donald L. Armstrong — Date: 11-10-09

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IPNI Staff Honored at 2009 ASA-CSSA-SSSA Annual Meetings

Three members of the scientific staff of IPNI were recognized for their achievements during the recent International Annual Meetings of the American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America (ASA-CSSA-SSSA) in Pittsburgh. They are:

- Dr. Clifford S. Snyder, elected Fellow of SSSA
- Dr. Robert L Mikkelsen, Agronomic Industry Award
- Dr. T. Scott Murrell, Soil Science Industry Award

Dr. Snyder is Nitrogen Program Director of IPNI and is based in Conway, Arkansas. He is also an adjunct professor in the University of Arkansas Crop, Soil and Environmental Sciences Department. He earned his B.S and M.S. degrees at the University of Arkansas, and his Ph.D. at North Carolina State University. Dr. Snyder's education and outreach program focuses on the efficient and effective use of fertilizer N in crop production, in North America and globally. He has served as a Division Chair in SSSA and ASA (elected Fellow in 2002). He has been active in the American Association for the Advancement of Science, regional nutrient management conferences, and Certified Crop Adviser training. He has served on Environmental Protection Agency (EPA) science committees in addressing hypoxia in the Gulf of Mexico, greenhouse gas emissions, and other environmental challenges. Dr. Snyder currently serves on the International Nitrogen Initiative-Science Advisory Committee. Fellow is the highest recognition bestowed by the Society. Fellows are nominated by other members of the Society, and only up to 0.3% of Active and Emeritus Members may be elected to Fellow.

Dr. Mikkelsen is Western Region Director of IPNI and is located in Merced, California. He conducts training on nutrient management throughout the region. He previously was on the faculty at North Carolina State University and a research scientist with the Tennessee Valley Authority. Dr. Mikkelsen received a B.S. from Brigham Young University and Ph.D. from University of California-Riverside. He is a fellow in ASA and SSSA and serves on the board of directors for SSSA and the American Society for Horticultural Science. The Agronomic Industry Award recognizes outstanding performance by a private sector agronomist in the development, acceptance, and implementation of agronomic programs, practices, and/or products, based on professionalism, integrity, and credibility.

Dr. Murrell is Northcentral Region Director of IPNI and is located in West Lafayette, Indiana. Dr. Murrell received a B.A. and M.S. from Purdue University and Ph.D. in soil science at Texas A&M University. He was with the Potash & Phosphate Institute for 10 years prior to establishment of IPNI in 2007. In the Northcentral U.S. Region, corn and soybean are the dominant crops. Dr. Murrell's primary area of interest is researching flexible, site-specific nutrient recommendation approaches that are profitable, environmentally responsible, and scientifically sound. The Soil Science Industry Award recognizes outstanding contributions to soil, environment, natural resource, agricultural, and related sciences by a practicing professional or scientist in the private sector. Criteria include: activities pertinent to improving understanding of soil science, and to the development, advancement, and application of technologies for improving environmental quality, agricultural productivity and profitability; promotion and support of the soil, environmental, and agricultural science professions; and impact of professional activities on communities. Professionalism, integrity, and public service are important qualifications. BC

Abbreviations and notes: N = nitrogen.

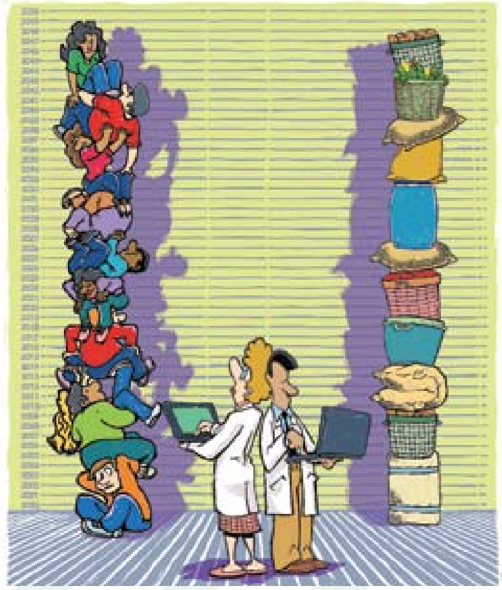
Dr. Snyder, right, receives the SSSA Fellow Award from SSSA President Paul Bertsch, University of Kentucky.

Dr. Mikkelsen, right, receives the Agronomic Industry Award from ASA President Dr. Mark Alley, Virginia Tech.

Dr. Murrell, right, receives the Soil Science Industry Award from SSSA President Paul Bertsch, University of Kentucky.

Fertilizer and Food Production

World demand for food will increase sharply over the coming years as population is expected to increase by almost 40% from the current 6.7 to an expected 9.2 billion by 2050. Aside from the increased population projections, another factor impacting food concerns is consumer affluence, where a shift toward more meat consumption is seen in countries where diets have traditionally been more grain-based. For example, since 1995 meat consumption in the developing world has increased by 16% and in China it has increased by almost 40%. This increasing demand for meat protein means greater demand for feed grains.



Food production will clearly need to increase to meet the demands of a larger and more affluent population. One report (The Millennium Project, State of the Future, 2008) indicated that food production will have to increase by 50% by 2013 and double in 30 years to help solve the food issue. Increased food production will require intensified production since the amount of available arable land is finite. Genetics and biotechnology will help intensify production, as will fertilizer and other inputs.

A fundamental question that the fertilizer industry has sought to address for some time now is "How much of crop production is attributable to fertilizer input?" I was lead author of an *Agronomy Journal* paper addressing this question, published in 2005. Several long-term studies in the USA, England, and the tropics, along with the results from an agricultural chemical use study and nutrient budget information, were evaluated. A total of 362 seasons of crop production were included in the long-term study evaluations. Crops utilized in these studies included corn, wheat, soybean, rice, and cowpea. The average percentage of yield attributable to fertilizer generally ranged from about 40 to 60% in the USA and England and tended to be much higher in the tropics. The paper concluded that the commonly cited generalization that at least 30 to 50% of crop yield is attributable to commercial fertilizer nutrient inputs is a reasonable, if not conservative estimate.

Intensification of production and increasing yield on limited arable land is clearly important in securing an adequate food supply, and the importance of the role of fertilizer in this is undeniable. However, another important aspect of fertilizer and its role in food production involves crop quality and human health. There are many affects of nutrient input on crop quality, and among the more interesting is the impact fertilizer inputs can have on human heath affecting compounds. IPNI has published several papers and supported studies in this area over the past few years. One of the most noteworthy studies involved cantaloupe in the Rio Grande Valley of Texas. This study showed that foliar K applications during cantaloupe fruit development and maturation improves fruit marketable quality by increasing firmness and sugar content, and fruit human health quality by increasing ascorbic acid, beta-carotene, and K levels (Lester et al., 2007, *Better Crops*).

Meeting the world's escalating food needs cannot be achieved without fertilizer input. Without fertilizer, it is estimated that the world would produce only about half as much staple foods and more forested lands would have to be put into production. Inorganic commercial fertilizer plays a critical role in the world's food security and is important from both the yield and food quality perspectives.

Intensification of production will be increasingly essential to the challenge meeting future food demands. However, this intensification must be done so as to minimize environmental impact. That's why the concept of the Four Rights (4R) Nutrient Stewardship framework (right fertilizer source-rate-time-place) is so timely. For more information, visit the IPNI website at >www.ipni.net/4r<.

Mike Stewart
IPNI North America Program
Southern and Central Great Plains Director

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