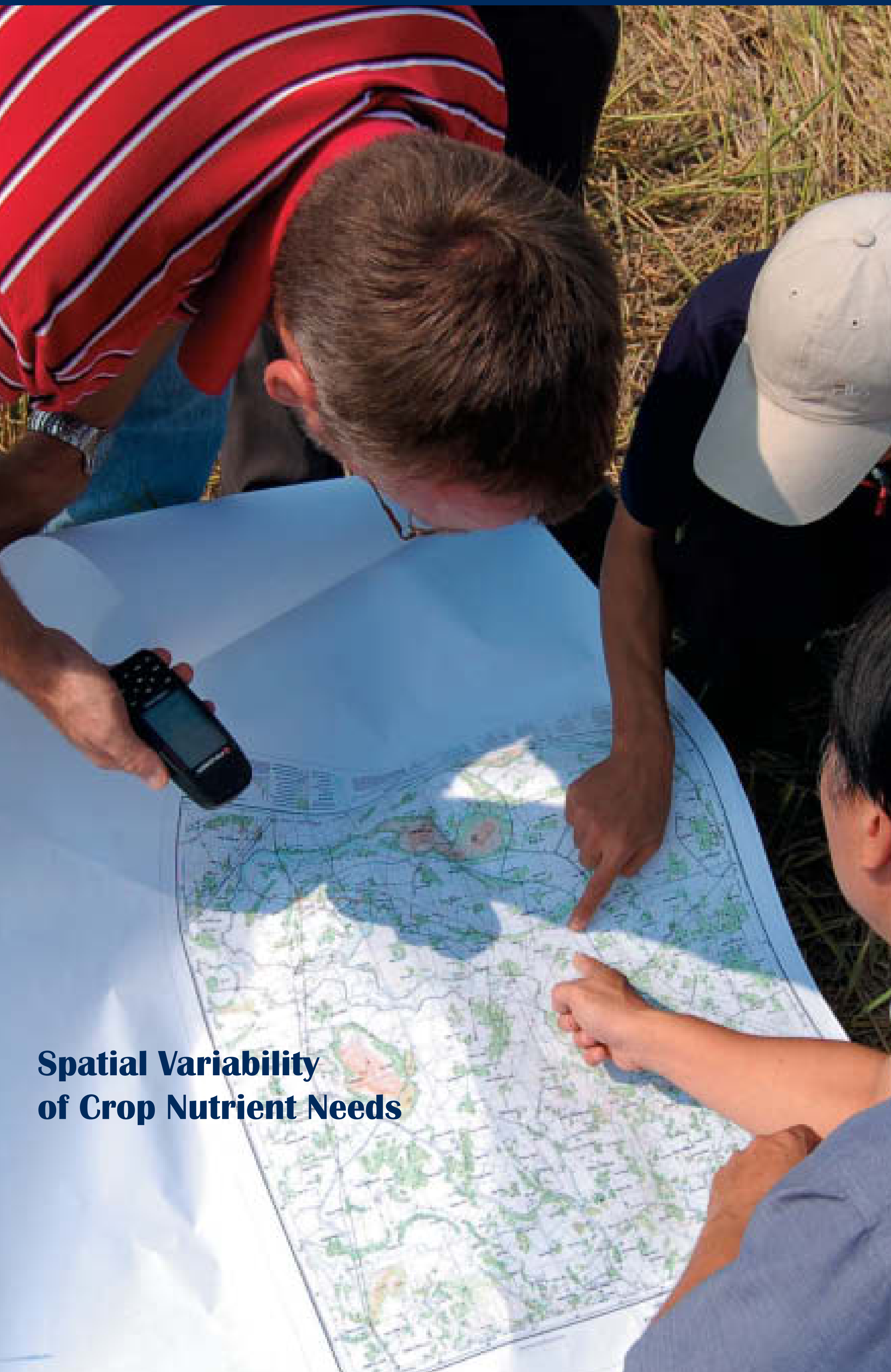
BETTER CROPS
WITH PLANT FOOD

A Publication of the International Plant Nutrition Institute (IPNI)

2007 Number 3



Spatial Variability of Crop Nutrient Needs

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Vol. XCI (91) 2007, No. 3

Our cover: Scientists plan a survey of degraded soils in Vietnam.
Photo by Dr. C. Witt, IPNI

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

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

C O N T E N T S

Does Potassium or Chloride Play a Dominant Role in Suppression of Corn Stalk Rot?

By Ji-yun Jin, Xiaoyan Liu, and Ping He

Corn stalk rot is a serious and widespread disease in the main corn production areas of China. Previous research has indicated that KCl plays a significant role in suppression of corn stalk rot. This study compared the effects of K and Cl nutrition, and showed that K played an important role in the suppression of the disease.

Stalk rot is a disease of increasing importance to corn production in China. The average annual yield loss in China due to stalk rot infection is approximately 20% and in individual fields may reach 50%. Potassium has long been the nutrient most associated with plant disease reduction. Potassium fertilizer application is one of the few effective measures to suppress corn stalk rot. A 12-year fixed site field trial in Jilin Province showed that KCl application decreased the incidence of corn stalk rot by 48% (Liu et al., 2007). However, insufficient attention has been paid to the question of which element in KCl plays the dominant role in the suppression of corn stalk rot…an inadequacy addressed by this research.

Jilin is designated the "Corn Belt" of China due to its top ranking in annual sown area (Jia, 2004). A field experiment was conducted in the Gongzhuling region of Jilin in 2005 using a set of treatments consisting of a check (CK) and six combinations of K and Cl (K_{120}, K_{240}, $K_{120}Cl_{90}$, $K_{240}Cl_{180}$, Cl_{90}, and Cl_{180}) laid out in a randomized complete block design with four replicates. All treatments had equal applications of N and P. Plot area was 40 m^2. Soil pH and nutrient status at the 0 to 20 cm depth are shown in **Table 1**. Available nutrients in the soil were determined by ASI soil analysis methods (PPI/PPIC Beijing Office, 1992). Based on soil test results, applications of S, Zn, and Cu were done before sowing, at rates of 20, 10, and 1.0 kg/ha, respectively. Since soil Ca concentration was abundant and crops in the region have not responded to Ca fertilization, $CaCl_2$ was used to evaluate the effect of Cl on corn yield and disease severity. Potassium chloride was used to study the combined effect of K and Cl. Potassium nitrate was used to study the effect of K alone. The amounts of fertilizer used in the treatments are given in **Table 2**. The study used two commercial corn hybrids including Jidan 180, which is moderately resistant to stalk rot, and Jidan 327, which is considered susceptible to stalk rot. The plant density was 50,000 plants/ha. The incidence of corn stalk rot was investigated prior to harvest.

The treatment created obvious differences in growth between resistant and susceptible varieties at plant jointing stage (**see photos**). Prior to harvest of both varieties, significant reductions in stalk rot incidence, as well as yield increases, occurred in response to K and KCl, but not to Cl alone (**Table 3**). All K and KCl treatments reduced disease severity by 50 to 64%, and increased yield by 13 to 23% in Jidan 327. In Jidan 180, stalk rot was decreased by 44 to 60% and yield was increased by 20 to 29% compared to the CK. Thus, stalk rot was more effectively suppressed in the susceptible variety, but yield was enhanced to a larger degree with the resistant variety.

Effects of K, Cl and KCl on the growth of Jidan 180 (top) and Jidan 327 (bottom) corn hybrids at jointing stage.

No significant differences in disease incidence and yield were observed between the two fertilization rates of KCl and

Table 1. Initial soil characteristics at the experimental site, Jilin.

OM	NH_4^+	P	K	Ca	Mg	S	B	Fe	Mn	Cu	Zn	Cl	pH
%	----- mg/kg -----			--- g/kg ---		-------------- mg/kg --------------							
2.4	8.6	5.9	42.4	3.0	0.4	12.9	1.8	102.5	12.8	2.7	1.0	30.2	5.8

Abbreviations and notes for this article: K= potassium; Cl = chloride; KCl = potassium chloride; KNO_3 = potassium nitrate; K_2SO_4 = potassium sulfate; S = sulfur; Zn = zinc; Cu = copper; Ca =calcium; N = nitrogen; P = phosphorus; ASI = Agro Services International.

The corn leaves in the left rows received no K fertilizer and appeared dull gray-green, while the leaves in the right rows with K application were still green.

Cl. Stalk rot was reduced with the addition of K, regardless of source.

For Jidan 180, when K (as KNO_3) application increased from 120 to 240 kg/ha, stalk rot incidence was unaffected, but grain yield decreased. The degree of yield loss in other K and KCl supplying treatments may have been partially influenced by stalk rot incidence, but it appears nutrient imbalance may have exerted a larger effect. Ash and Brown (1991) found a similar result showing that increased disease did not correlate with yield losses, but N fertilizer application rate had a large influence on the yield-loss relationship.

For both varieties, 120 kg K_2O/ha seemed most appropriate, and 240 kg K_2O/ha excessive, to maintain high yields at this site. No positive interactions between K and Cl were detected at the 120 kg/ha rate, but there was evidence that Cl may help to moderate the yield-dampering effects of the 240 kg K_2O/ha rate applied to Jidan 180.

Heckman (1998) found that the incidence of corn stalk rot was 67% lower with KCl application, compared to K_2SO_4 application at an equivalent K rate. This result suggests that

Stalk lodging and ear dropping are the typical symptoms of corn stalk rot. Stalk rot in plots without K application (top) was more severe than that with K application (bottom) in September.

Table 2. Nutrient application rates for the set of treatments.

	$Ca(NO_3)_2$	$Ca(H_2PO_4)_2$	KNO_3		KCl		$CaCl_2$
Treatment	N	P_2O_5	K_2O	N	K_2O	Cl	Cl
CK	200	120	–	–	–	–	–
K_{120}	158	120	120	43	–	–	–
K_{240}	114	120	240	86	–	–	–
$K_{120}Cl_{90}$	200	120	–	–	120	91	–
$K_{240}Cl_{180}$	200	120	–	–	240	182	–
Cl_{90}	200	120	–	–	–	–	91
Cl_{180}	200	120	–	–	–	–	182

Table 3. Effects of K and Cl^- on the stalk rot incidence and yield of corn.

	Jidan 180				Jidan 327			
Treatment	Disease incidence, %	Disease control,%	Yield, kg/ha	Yield increase, %	Disease incidence, %	Disease control,%	Yield, kg/ha	Yield increase, %
CK	24.6 a[1]	—	7,114 c	—	34.1 a	—	6,925 c	—
K_{120}	13.7 b	44.4	9,162 a	28.8	17.1 b	50.0	8,544 a	23.4
K_{240}	12.4 b	49.6	8,546 b	20.1	12.3 b	63.8	7,839 ab	13.2
$K_{240}Cl_{90}$	10.8 b	55.9	8,615 ab	21.1	13.8 b	59.7	8,164 a	17.9
$K_{240}Cl_{180}$	9.9 b	59.8	9,050 ab	27.2	12.4 b	63.6	8,252 a	19.2
Cl_{90}	17.1 ab	30.3	7,373 c	3.6	31.8 a	6.8	6,340 c	-8.5
Cl_{180}	17.3 ab	29.8	7,166 c	0.7	30.4 a	10.8	6,509 c	-6.0

[1]Means within a column followed by different letters are significantly different (LSD Test, $p<0.05$).

Steven B. Phillips Joins Staff of IPNI as Southeast Region Director

Dr. Steven B. Phillips

Dr. Steven B. Phillips joined the staff of IPNI as Southeast Region Director effective June 1, 2007. He has responsibility for agronomic programs of the organization in the states of Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, Missouri, North Carolina, South Carolina, and Tennessee.

"We welcome Steve Phillips to the staff of IPNI and know he will be a great asset to the programs of this new organization," said Dr. Terry L. Roberts. "He has a strong background in research and extension programs focused on applied soil fertility and plant nutrition as related to production agriculture. His record of both academic and extension publications and presentations is impressive."

Dr. Clifford S. Snyder of Conway, Arkansas, served as Director of the Southeast Region and previously the Midsouth Region of IPNI (formerly the Potash & Phosphate Institute) since 1995. He was recently appointed to the new position of Nitrogen Program Director and coordinates IPNI efforts dealing with environmental issues associated with N fertilizer use in agriculture, both in North America and internationally.

A native of Oklahoma, Dr. Phillips holds a B.S. degree (1993) from Cameron University in Lawton, and M.S. and Ph.D. (1999) degrees from Oklahoma State University at Stillwater. From 1999 until June 2005 he was Assistant Professor, Soil Fertility and Plant Nutrition, Department of Crop and Soil Environmental Sciences, Eastern Shore Agricultural Research and Extension Center (AREC), Virginia Tech.

He became Associate Professor in July 2005 and maintained a 75% research/25% extension responsibility. The majority of his research dealt with efforts to improve the fertilizer use efficiency of various field and vegetable crops. A portion of this work focused on developing an optical sensor-based fertilization system to be used for winter wheat and corn production. Another area of Dr. Phillips research was broiler litter management.

The extension component of his work involved dissemination of production-related information to growers, industry, and county extension personnel, including soil fertility recommendations, assisting with soil test interpretations, and various presentations of research results. Dr. Phillips also carried responsibility for advising graduate students. In recent years, Dr. Phillips has been involved in several international workgroups and collaborative research projects with scientists in Argentina, Mexico, India, and other countries.

His professional affiliations include membership in the Soil Science Society of America, American Society of Agronomy, Crop Science Society of America, and others. BC

Cl played an important role in the suppression of the disease. In contrast, this research indicates that Cl plays a less important role in stalk rot suppression than K. This inconsistency may be due to differences in nutrient status of the test soils. Sanogo and Yang (2001) reported that soil amendment with KCl when the soil was not deficient in K resulted in 36% decrease in the severity of soybean sudden death syndrome (SDS), a soil-born disease. Conversely, disease severity was increased by 43% with K_2SO_4 application, and by 45% with KNO_3, compared to the study's controls. Thus, Cl was helpful in reducing SDS and K application was not found beneficial. A comparison of the available K concentration (0 to 20 cm depth) between this research and Heckman's U.S. study finds the initial K fertility in the U.S. study to be 92 mg/kg, which is over twice the level measured in this work (**Table 1**). Additionally, soil Cl in the 0 to 30 cm soil layer was only 6 mg/kg (low) in Heckman's experiment, while this study's soil Cl concentration in 0 to 20 cm layer was 30 mg/kg. Therefore, under conditions of soil K deficiency and Cl sufficiency, the influence of K nutrition on corn stalk rot was much more strongly pronounced than the influence of Cl. Apparently the result is opposite under soil K sufficiency and Cl deficiency.

In conclusion, the role of K and Cl in disease suppression must be examined in conjunction with the soil nutrient status. Therefore, whether K or Cl play the dominant role in corn stalk suppression will depend on the K and Cl status of the soil. A well-balanced fertilization strategy is necessary for both yield increases and disease control. BC

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Acknowledgments

We thank Professor Kuan Zhang, Professor Xiu-fang Wang, and Professor Qi-ming Jin, Jilin Academy of Agricultural Sciences, for their help in managing these field experiments and in investigating the incidence of corn stalk rot.

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Biuret in Urea Fertilizers

By R.L. Mikkelsen

In the past, urea manufacturing processes sometimes resulted in fertilizers with elevated biuret concentrations. In high concentrations, biuret interferes with internal N metabolism and hinders protein formation in plants. Biuret is degraded by many soil microorganisms, but the rate is relatively slow. Modern urea manufacturing typically results in biuret concentrations less than 1.0 to 1.3%, which does not pose problems for most uses. There are some plant species that appear to be especially sensitive to biuret, so "low-biuret" urea should be used for foliar application in these situations.

Urea has become the leading form of N fertilizer worldwide. Urea, a naturally occurring compound, can also be made by reacting carbon dioxide with ammonia at high temperature and pressure. Its high N content (46% N) makes urea economical to produce, transport, and deliver to the farm.

Two concerns are sometimes expressed by growers using urea as a N source for crop nutrition. First, when urea remains on the soil surface, a portion of the applied N may be lost through NH_3 volatilization…thereby diminishing its fertilizer value. When urea is first applied to soil, it generally reacts quickly with soil enzymes (urease) to convert to NH_4^+ then to NH_3 (**Figure 1**) which may be lost as a gas. Considerable effort has been made to understand this NH_3 loss pathway, resulting in urea coatings (such as controlled-release fertilizers), additives (such as urease inhibitors), and management practices that can substantially reduce these losses.

Reaction 1:

$$CO(NH_2)_2 + H^+ + 2H_2O \xrightarrow{\text{urease}} 2NH_4^+ + HCO_3^- \text{ (urea hydrolysis)}$$

urea — urease

Reaction 2:

$$NH_4^+ \rightarrow NH_3 + H^+ \text{ (ammonia volatilization)}$$

Figure 1. Typical breakdown of urea by soil enzymes to form ammonium (NH_4^+) and ammonia (NH_3).

A second concern related to urea fertilization is potential biuret toxicity for growing crops. When molten urea is heated near or above its melting point (132 °C or 270 °F) during manufacturing, several different compounds can be formed…including biuret (**Figure 2**). Biuret can be toxic to plants at elevated concentrations, whether applied to soil or foliage. Although modern urea manufacturing methods now consistently result in low biuret concentrations, questions still arise regarding potential hazards associated with biuret.

Biuret in Soils

Many years ago, researchers found that plant growth was reduced or completely eliminated following high applications of biuret to soils, and this growth suppression often persisted for a period of many weeks. Although the ability to degrade biuret is widespread among soil microorganisms, microbial growth is only half as fast with biuret as a N source as it is with urea. The presence of biuret also decreases the rate of nitrification in soil.

Foliar application effectively supplies nutrients for many orchard crops.

Seedling Damage

When urea with elevated biuret is placed adjacent to seeds, toxicity may result to the geminating plant. Some of this damage is due to the NH_3 evolved from the urea during normal hydrolysis, but biuret may make the harsh condition more severe. The extent of biuret damage to seedlings depends on the crop, the biuret concentration, and the fertilizer placement. Neither urea nor urea which contains biuret should be placed directly with a seed during planting. If the fertilizer is separated from

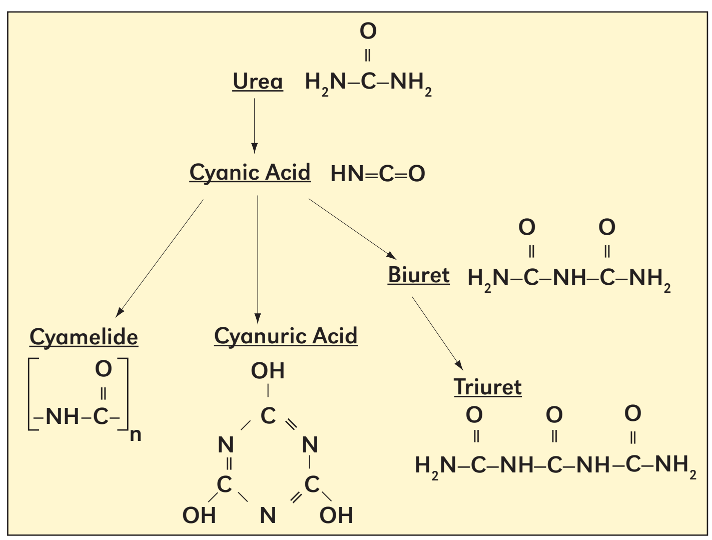

Figure 2. Possible reaction products formed from urea during exposure to high temperature.

Abbreviations and notes for this article: N = nitrogen; NH_4^+ = ammonium; NH_3 = ammonia the seed by a small volume of soil, toxicity problems are greatly diminished. Amending the urea with a small amount of urease inhibitor will also reduce these adverse affects.

Soil Application of Biuret

Many studies have been done to determine the maximum biuret concentration tolerated by crops. The specific crop sensitivity depends on many factors such as the plant species, soil properties, the method and timing of fertilizer application, and both the concentration and total amount of biuret applied.

The soil properties on which the biuret-exposed crop is grown are important in determining potential toxicity. Biuret is not retained in soil and is easily leached. Plants are generally less sensitive to biuret when it is applied to soils containing appreciable amounts of clay or organic matter, or of low pH.

The specific toxic agent associated with biuret in the root zone is not known. It has been considered that cyanuric acid or nitrite may accumulate in the soil following biuret application and contribute to plant toxicity. Although these compounds can be injurious to plants, biuret by itself is also harmful.

Many crops can tolerate large amounts of biuret applied with urea if it is not in direct contact with the seed. A general guideline for safe use of urea applied to soil would permit a maximum 2% biuret in urea. Many crops are not adversely affected until biuret concentrations greatly exceed this level, which is greater than the 1.0% biuret commonly found in most urea currently produced in North America. There are a few plant species (such as citrus and pineapple) that do not tolerate elevated levels of biuret.

Citrus leaves damaged by biuret and urea application.

Foliar Application of Biuret

During the 1950s, foliar biuret damage was first noted following urea sprays on sensitive avocado, citrus, and pineapple. Since that time, considerable effort has been devoted to determining the safe threshold concentration of biuret in foliar sprays of urea. As with soil application, some plant species are more tolerant of biuret than others, but the allowable concentration of biuret in urea intended for foliar sprays is much lower than for soil application. Urea and biuret move readily into the leaves of many plants, making the potential for adverse effects greater with foliar fertilization.

Foliar application of urea can be extremely beneficial in some circumstances for plants. Several cereal, vegetable, and perennial crops respond favorably to foliar applications of urea with increased growth, yield, and quality. These benefits can include boosting grain N concentrations, reducing N losses through leaching and denitrification, and supplying N when root uptake is limited. However, foliar-applied nutrients may be directly absorbed by plants (without the buffering effects of the soil), so careful attention must be paid to this practice to do it properly.

Following foliar application of urea containing 0.5% biuret to potatoes, visual symptoms of yellow leaves, upward leaf rolling, and necrotic leaf margins have been noted. Application of urea and biuret on oranges resulted in damaged leaves, where the apical portion of the leaf was the most sensitive to biuret (**see photo**). These yellow leaves never regained their normal color, although the new flush of growth appeared normal. Because biuret is not rapidly metabolized by plants, repeated spray applications of urea and biuret may have a cumulative effect, especially with perennial crops.

Effects of Biuret on Plant Metabolism

Plants are not able to rapidly metabolize biuret. In one experiment, biuret still remained in the leaves of orange trees eight months after foliar application. Soil-applied biuret similarly accumulates in plants for long periods of time. The exact mechanism of biuret damage to plants is still uncertain, but the harmful effects of high concentrations have been well documented.

When present in elevated concentrations, biuret interferes with normal protein synthesis and internal N metabolism in the plant. Lower N concentrations are typically found in biuret-damaged leaves than in healthy urea-treated leaves. Biuret also disrupts normal activity of many important plant enzymes…increasing some enzymes and decreasing others…compared with healthy leaves.

Although biuret in urea can be damaging to plants when present in high concentrations, modern manufacturing processes have greatly reduced the severity of this problem. Early urea fertilizer manufacturing facilities often produced urea containing more than 5% biuret. Foliar application of urea solutions containing 1% biuret is acceptable for many common agronomic crops. However, for foliar fertilization of some sensitive crops, urea with especially low concentrations of biuret (less than 0.3 % biuret) may be required. If the sensitivity of a specific crop to biuret in foliar sprays is not known, it is advisable to start with low-biuret urea until the sensitivity has been determined.

The modern N fertilizer industry produces urea that is remarkably safe, consistent, and effective for enhancing plant growth. Urea has many properties that make it the most commonly used N fertilizer in the world. Biuret toxicity problems are generally rare, but special attention should be made for fertilization of especially sensitive crops. BC

For more information and a list of scientific references, visit this URL: www.ipni.net/biuret

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Liming Indexes for Soybean in Established No-Till Systems

By Antonio Nolla and Ibanor Anghinoni

Researchers re-examine the definition of lime requirements for well established no-tillage systems or for those directly established from previously uncultivated natural grasslands.

Conventionally tilled soils being converted into no-tillage production systems, or natural grasslands being directly converted into no-till, tend to accumulate large amounts of crop residue. Within a short period of time, they can also develop strong pH and nutrient (i.e., P, K, Ca, and Mg) gradients. In concert, these changes within the topsoil will act to decrease the potential for Al toxicity through increased complexation with fulvic and humic acids derived from soil organic matter, and low molecular weight ligands resulting from further crop residue decomposition. Other observed changes include decreased exchangeable Al and Al saturation on the CEC, decreased Al activity within the soil solution, and increased soil P availability.

In no-till systems, high yields are possible even under strongly acidic soil pH conditions. There is a strong possibility that adoption of liming criteria designed for systems under conventional soil tillage can over-estimate the lime requirement for established no-tillage systems in southern Brazil. Another important challenge for these no-tillage systems is the identification of an appropriate soil layer thickness, and soil sampling frequency, to be used for assessing topsoil acidity. The depth of soil pH and nutrient gradients does increase with time as more plant residues are deposited and surface applications of lime and fertilizers continue under no-till. When climate and soil conditions favor corrective action, surface application of lime can correct soil acidity within the top 10 cm up to 4 years after lime application (Miyazawa et al., 1993; Franchini et al., 1999; Anghinoni and Salet, 1998).

This study explored various options for liming indexes in soybean after 8 years of no-tillage in an acid clayey Oxisol previously under conventional tillage, and before that, natural grassland. Three levels of lime were applied at the establishment of the conventional tillage cropping system. Soil sample results after 8 years of no-till still present a wide range of soil acidity indexes (**Table 1**).

Liming criteria, the values indicating the necessity for lime, were established according to the relationship between soybean yield and six indexes using two soil depths, 0 to 10 cm and 0 to 15 cm. All relationships were significant regardless of soil depth or initial soil condition prior to no-till establishment (**Figure 1A and 1B**). The comparison between soil sample depths found better relationships with soybean yields using the 0 to 15 cm soil layer, despite the larger range of the acidity parameters found in the 0 to 10 cm soil layer.

All the response curves, except exchangeable Al/Ca + Mg, were curvilinear, with very good fitness and significance. The exchangeable Al/Ca + Mg relation was linear, and was not further considered as a suitable lime index in this present work. The resulting liming criteria obtained for both initial tillage conditions are provided in **Table 2**. The average acidity indexes values for the 0 to 15 cm soil layer can be considered lower than current liming criteria values for soybean in Brazil. It is apparent from these results that exchangeable Al can be considered less toxic to soybean within a no-tillage system.

Liming requirements for soybean in conventional tillage may be higher than for established no-till systems in southern Brazil.

Currently, the 0 to 10 cm layer is the recommended soil sample depth for determining lime surface application within well established no-till fields in southern Brazil. It is important to consider that two of the three more commonly used liming criteria in Brazil [i.e., pH (water) and base saturation], were very similar when evaluated either in the 0 to 15 cm or 0 to 10 cm soil layer. However, the indexes for exchangeable Al and Al saturation were considerably higher in the 0 to 15 cm layer as compared with the 0 to 10 cm layer, which presented higher variability.

Table 1. Range of soil chemical attributes in the 0 to 20 cm soil layer after 8 years under no-tillage after application of lime.

Chemical attribute	Initial condition	Range
Water pH	Conventional tillage	4.3 to 5.5
	Natural grassland	4.1 to 5.7
$CaCl_2$ pH	Conventional tillage	3.6 to 4.8
	Natural grassland	3.3 to 5.1
Exchangeable Al, $cmol_c/kg$	Conventional tillage	2.5 to 0.2
	Natural grassland	2.9 to 0.5
Bases saturation, %	Conventional tillage	16 to 61
	Natural grassland	11 to 71
CEC[1], $cmol_c/kg$	Conventional tillage	12.4 to 14.6
	Natural grassland	13.0 to 16.2

[1]CEC estimated by 0.5 mol/L calcium acetate method.

Abbreviations and notes for this article: P = phosphorus; K = potassium; Ca = calcium; Mg = magnesium; Al = aluminum; CEC = cation exchange capacity.

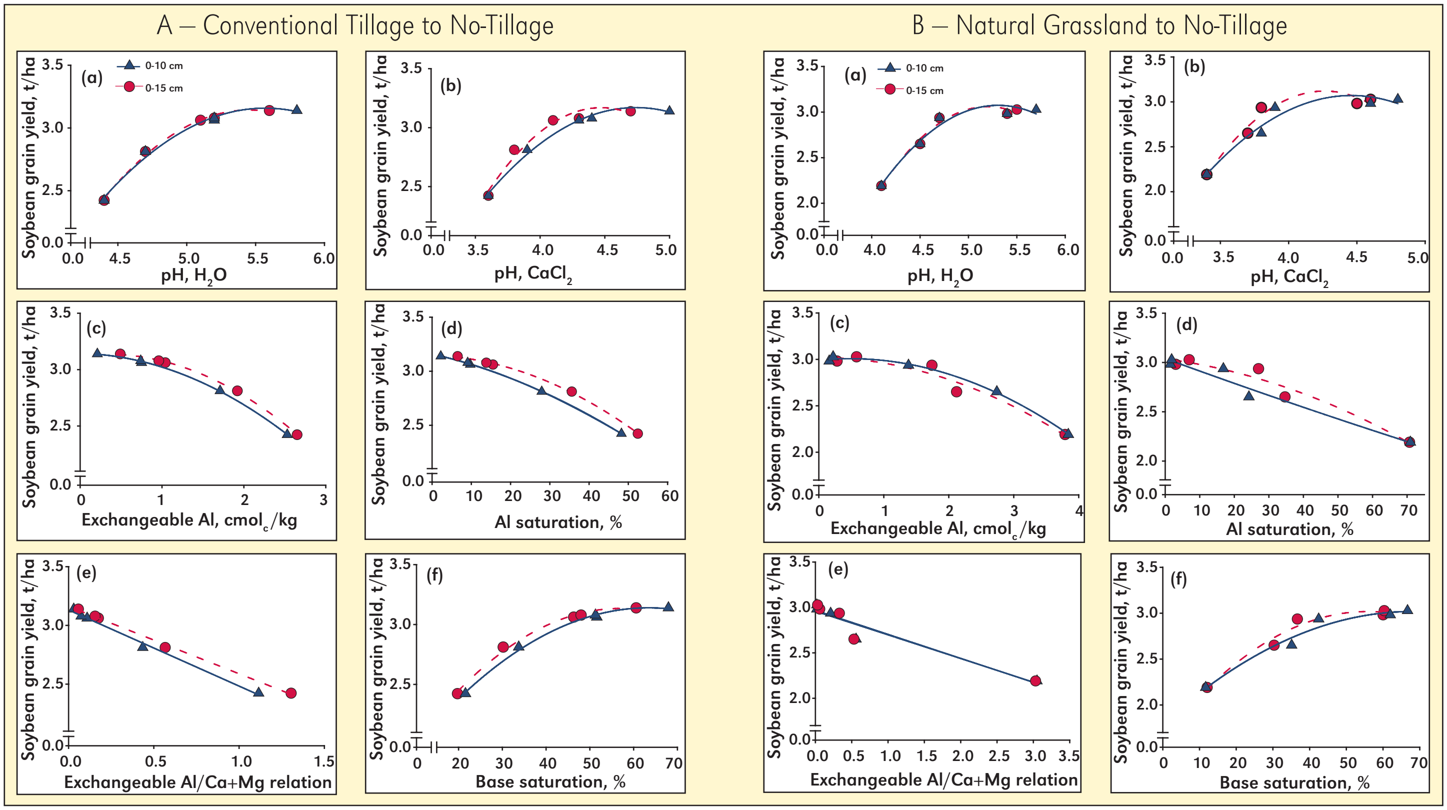

Figure 1. Relationship between soybean grain yield and pH H_2O (a), pH $CaCl_2$ (b), exchangeable Al (c) Al saturation (d), exchangeable Al/Ca+Mg relation (e), and base saturation (f) in two layers of soil under no-tillage for 8 years after application of lime rates in conventional tillage (A) and in natural grassland (B).

Liming criteria as determined by the 0 to 15 cm sample depth and both Al indexes were particularly more variable between the conventional tilled and natural grassland sites. Higher reference values for the latter case can be related to the site's direct conversion to no-till, which has maintained soil acidity characteristics more in line with those measured prior to the adoption of no-till.

In a related greenhouse study designed to determine if liming criteria could be established within a short-term experiment, undisturbed soil samples were collected from the field site using columns. Soybean growth behavior in the greenhouse, as affected by soil acidity, was similar to that observed for grain yield results obtained from the field. Relationships between soil acidity and soybean root and shoot growth were also curvilinear, with good fitness for all acidity indexes, in both soil layers, and initial soil condition prior to no-till (data not provided). Liming criteria were then determined (**Table 2**), which compared well with those obtained from the field experiment. However, it is important to note that the lime criteria based on root growth was most similar to results obtained in the field.

The soil sample depth for lime requirement determination

Table 2. Liming criteria for soybean based on different soil acidity indexes, and two soil sampling depths after 8 years of no-tillage.

Parameter	Initial condition	pH-H_2O		pH-$CaCl_2$		Exchangeable Al, $cmol_c/kg$		Al saturation, %		Bases saturation, %	
		0 to 10[2]	0 to 15	0 to 10	0 to 15	0 to 10	0 to 15	0 to 10	0 to 15	0 to 10	0 to 15
Grain yield	Conventional	5.6	5.5	4.7	4.5	0.29	0.32	3	11	64	60
	Natural grassland	5.3	5.2	4.5	4.3	0.47	0.79	3	23	60	62
	Average	5.5	5.4	4.6	4.4	0.38	0.56	3	17	62	61
Root biomass[1]	Conventional	5.6	5.4	4.8	4.5	0.31	0.68	13	11	61	55
	Natural grassland	5.7	5.1	4.8	4.2	0.31	1.11	1	16	75	61
	Average	5.7	5.3	4.8	4.4	0.31	0.90	7	13	70	58
Root length[1]	Conventional	5.5	5.7	4.7	4.7	0.64	0.74	10	10	59	63
	Natural grassland	5.4	5.2	4.5	4.3	0.13	0.85	9	13	80	57
	Average	5.5	5.5	4.6	4.5	0.39	0.80	10	12	69	60
Shoot biomass[1]	Conventional	5.4	5.3	4.6	4.4	0.53	0.80	1	14	56	63
	Natural grassland	5.3	5.1	4.4	4.2	0.96	0.89	1	14	47	61
	Average	5.4	5.2	4.5	4.3	0.75	0.85	1	14	52	62

[1]Determined using undisturbed soil core samples and soybean grown under greenhouse conditions.
[2]Soil layer depth, cm.

IPNI Crop Nutrient Deficiency Photo Contest—2007

While the classic symptoms of crop nutrient deficiencies are not as common in fields as they were in the past, they do still occur. To encourage field observation and increase understanding of crop nutrient deficiencies and other conditions, the International Plant Nutrition Institute (IPNI) is sponsoring a photo contest during 2007.

"We hope this competition will appeal to practitioners working in actual production fields," said IPNI President Dr. Terry Roberts. "Researchers working under controlled plot conditions are also welcome to submit entries. We encourage crop advisers, field scouts, and others to photograph and document deficiencies in crops."

Some specific supporting information is required for all entries, including:

- The entrant's name, affiliation, and contact information.
- The crop and growth stage, location, and date of the photo.
- Supporting and verification information related to plant tissue analysis, soil test, management factors, and additional details that may be related to the deficiency.

There are four categories in the competition: Nitrogen (N), Phosphorus (P), Potassium (K), and Other. Entries are limited to one per category (one individual could have an entry in each of four categories).

Cash prize awards are offered in each of the four categories as follows:

- First place = US$150
- Second place = US$75
- Third place = US$50

Photos and supporting information can be submitted until the end of calendar year 2007 (December 31, 2007) and winners will be announced in January of 2008. Winners will be notified and results will be posted at the website.

Entries are encouraged from all regions of the world. However, entries can only be submitted electronically as high resolution digital files to the organization's website, at **>www.ipni.net/photocontest<**.

For questions or additional information, please contact:

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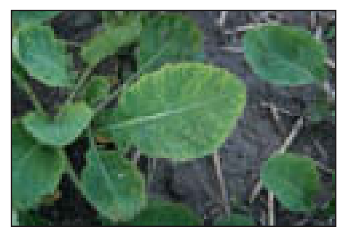
Shown at right are some photos as examples of deficiency symptoms. BC

Nitrogen deficiency in corn.

Phosphorus deficiency in cotton.

Potassium deficiency in soybeans.



Sulfur deficiency in canola.

in well established no-tillage systems converted from conventional tillage or natural grassland can be either 0 to 15 cm or 0 to 10 cm. Among the tested acidity indexes, pH (water) and percent base saturation were most suitable in assessing the lime criteria for soybean. Reference values from this research are lower than those currently being recommended. The lime criteria for no-tilled soils can also be quantified within short term experiments using undisturbed soil samples and soybean root growth parameters. BC

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Direct and Residual Effects of Balanced Fertilization in Field Crops of the Pampas

By Fernando García, Miguel Boxler, Jorge Minteguiaga, Ricardo Pozzi, Luis Firpo, German Deza Marin, and Angel Berardo

A long-term fertilization study in the central pampas of Argentina shows significant yield responses to NPS fertilization in corn, wheat, and full season and double-cropped soybean. Differences between the NPS and check treatments have increased over the past six years. Residual effects of balanced NPS fertilization include improved soil P and organic matter levels.

Crop production in the Pampas region of Argentina is generally affected by N and P deficiencies. In recent years, S has also been reported as a limiting nutrient for field crops. Several areas of the Pampas, such as southern Santa Fe and southeastern Cordoba, do not have updated local crop response and soil test calibration data either for N, P, S, or other plant nutrients.

The Southern Santa Fe Region of CREA (Regional Consortium of Agricultural Experimentation) is comprised of 12 groups of 10 to 15 farmers, located in southern Santa Fe, southeastern Cordoba, and northern Buenos Aires provinces in the central Pampas. The consortium's goal is to develop and exchange experiences and information on soil and crop management, farm business management, and product marketing. Total area planted to annual crops by these groups is approximately 200,000 ha. Main field crops are soybean, wheat and corn under rotations including three crops in two years as corn-wheat/soybean (C-W/S), or four crops in three years (C-S-W/S).

Corn and wheat are usually fertilized with N and P, and S fertilization has been incorporated as a standard practice in several fields in the last 4 to 5 years. Fertilizer rates have traditionally been lower than crop nutrient removal, resulting in the continuous depletion of native soil fertility. Traditional fertilization management focuses on the immediate crop. A lack of information exists on the long-term effects of improved fertilization strategies.

In 2000, a long-term fertilization study was established in eleven farmer fields of the CREA Region with the following objectives: i) to determine direct and residual crop responses to the application of N, P, S, and other nutrients including K, Mg, B, Cu, and Zn, ii) to evaluate diagnostic methodologies for N, P, and S fertilization of corn, wheat, and soybean; and iii) to evaluate the effects of nutrient management on soil properties. This article presents a synthesis of the more relevant results observed in the first 6 years of experimentation (2000-2005). Further information is available at Thomas et al. (2002, 2003), Blanco et al. (2004a and b), García et al. (2005a and b, 2006a and b), Boxler et al. (2006), and at the websites www.aacrea.org.ar and www.ipni.net.

Eleven similar experiments were started in the 2000/01 season under corn (**Figure 1**). After the first year, the experiments were divided in two groups: Five sites continued under a C-W/S rotation, and six sites under a C-S-W/S rotation. Soils at the different sites are classified as Typic Argiudolls or Typic Hapludolls. Fields were under continuous annual cropping for 5 to 60 years and under continuous no-tillage management for at least 5 years prior to 2000/01.

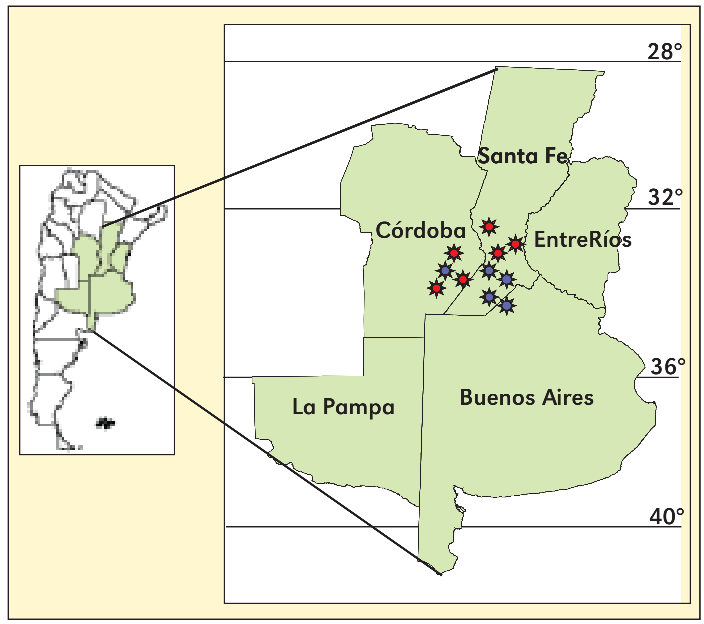

Figure 1. Location of the 11 experimental sites of the on-farm experimental network of the Southern Santa Fe Region of CREA in the central Pampas of Argentina. Blue stars indicate the sites under C-W/S rotation, red stars indicate the sites under C-S-W/S rotation.

Treatments included: 1) Check, 2) PS, 3) NS, 4) NP, 5) NPS, and 6) Complete with NPS plus K, Mg, B, Cu, and Zn. Treatments were repeated every year on the same plots to evaluate direct and residual fertilization effects. For all nutrients except N, rates applied to corn, wheat, or full season soybean were equivalent to grain nutrient removal + 10% (**Table 1**). Rates of N were estimated from local experiments with high-yielding crops. No N was applied on soybean. Treatments were set in a randomized complete block design with three replications at each site. Plot size was 10 to 20 m wide by 50 to 60 m long.

Soil analyses for Bray P-1 (0 to 20 cm), NO_3-N, and SO_4-S (0 to 60 cm) were performed every year for selected treatments. Soil organic matter; pH; exchangeable Ca for Bray P-1 (0 to

Abbreviations and notes for this article: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Ca = calcium; Mg = magnesium; B = boron; Cu = copper; Fe = iron; Zn = zinc; SOC = soil organic carbon; NO_3-N = nitrate-N; SO_4-S = sulfate-S; ppm = parts per million.

Table 1. Nutrient rates annually applied to each treatment of the on-farm experimental network of the Southern Santa Fe Region of CREA during the period 2000-2005.

	Check	PS	NS	NP	NPS	Complete
N[1]			120-150	120-150	120-150	120-150
P		30-40		30-40	30-40	30-40
K						18
Mg						10
S		20-25	20-25		20-25	20-25
B						1
Zn						2
Cu						2

[1]No N was applied in any treatment for full season soybean.

20 cm), NO_3-N, and SO_4-S (0 to 60 cm), Mg, K, and micronutrient concentrations including B, Cu, Fe, Mg, and Zn were determined (0 to 20 cm) at the beginning of the study and 4 years after. Nitrate sap concentration in wheat and corn stems, and chlorophyll meter readings (Minolta SPAD 502®) were determined for wheat and corn crops (data not shown).

Grain yield data were subjected to analysis of variance for each site/crop. Means separation was carried out by LSD test ($p<0.05$). Soil variables were related to grain yield and grain yield responses through regression analysis.

Averaged over both crop rotations, balanced fertilization with NPS increased grain yields by 49, 65, 7, and 20% compared to the check yields for corn, wheat, full-season soybean, and double-cropped soybean, respectively (**Figures 2 and 3**). Application of K, Mg, B, Cu, and Zn generally did not affect grain yields.

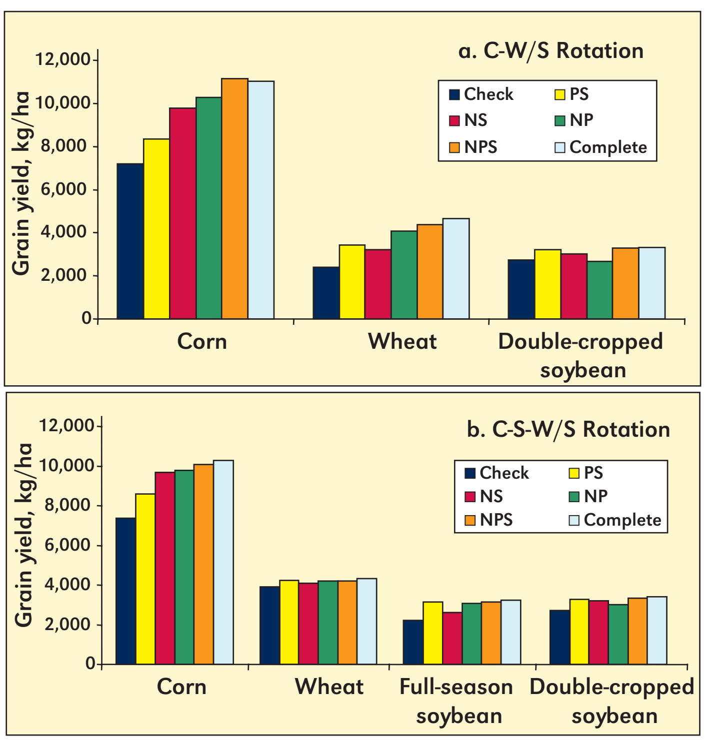

Figure 2. Average grain yields for the C-W/S (a) and C-S-W/S (b) rotations from 2000 to 2006. Nutrition network of CREA Southern Santa Fe.

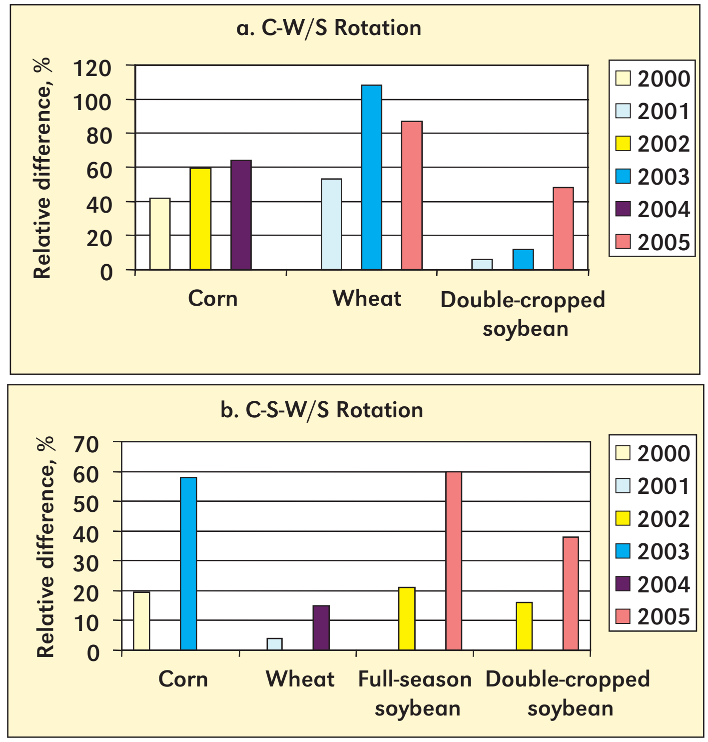

Figure 3. Relative grain yield difference between the NPS and check treatments for the C-W/S (a) and C-S-W/S (b) rotations from 2000 to 2006. Nutrition network of CREA Southern Santa Fe.

For corn, in 23 site/years responses were significant in 21, 8, 6, and 5 site/years for N, P, S, and NPS, respectively. For wheat, responses were significant in 5 of the 16 site/years for N, 11 site/years for P, 3 site/years for S, and 2 site/years for other nutrients. For full season soybean, in 11 site/years responses were significant in 1, 3, 2, and 3 site/years for N, P, S, and NPS, respectively. For double-cropped soybean, responses were significant in 1 of the 16 site/years for N, 3 site/years for P, 10 site/years for S, and 4 site/years for NPS.

Nitrogen response in corn and wheat was significantly related to soil NO_3-N availability at planting plus fertilizer N. Wheat yields of 3,600 kg/ha could be reached with N availability of 100 kg/ha, while corn yields of 10,300 kg/ha could be achieved with 200 kg/ha of N availability.

Phosphorus response was related to soil Bray P-1 for corn, wheat, and double-cropped soybean. Critical levels of soil Bray P-1 were estimated at 15 ppm for corn and wheat, and 13 ppm (at wheat planting) for double-cropped soybean. Responses to S were related to SO_4-S concentration at planting for corn, and full season soybean, but not for wheat (data not shown).

Frequency of responses and yield differences increased along the six seasons of evaluation as a consequence of residual effects that resulted in soil fertility buildup. **Figure 3** shows that relative grain yield differences between the NPS and check treatments have increased over the years as a result of improved versus soil nutrient depleting fertilization, respectively. Differences in Bray P-1 were found among treatments with and without P fertilizer, but residual effects of N or S fertilization could not be detected in soil NO_3-N or SO_4-S measurements. Depending on the rotation, average soil Bray P-1 increased by 2 to 3 ppm per year, in the NPS treatment which had an almost neutral P balance between P applied as

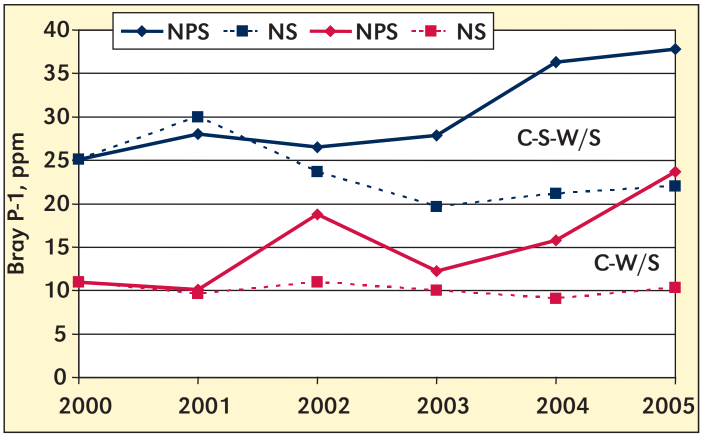

Figure 4. Evolution of soil Bray P-1 of the NPS and NS treatments averages of all sites, of the C-W/S (red lines) and C-S-W/S (blue lines) rotations from 2000 to 2006. Nutrition network of CREA Southern Santa Fe.

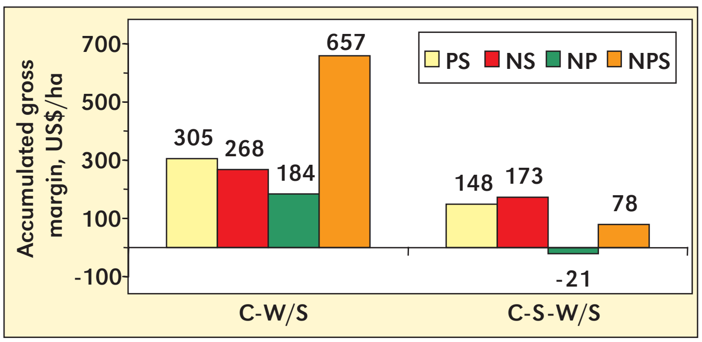

Figure 5. Accumulated gross margin of selected treatments in the 6 years of experimentation for the C-W/S and C-S-W/S rotations. Nutrition network of CREA Southern Santa Fe.

fertilizer and P removed in grains in both rotations (**Figure 4**). Soil Bray P-1 tended to decrease in the NS treatments by 0.05 to 1.5 ppm per year.

Comparison of SOC concentrations between the check and NPS treatments showed an average increase of 3.4 g C/kg soil after four seasons. However, these changes in SOC were highly variable among sites, from -5.2 to +10.3 g C/kg soil. Fertilization with NPS generally tended to decrease soil pH, -0.4 to +0.1 units depending on the site. No significant differences in cation and micronutrient concentrations were observed between the check and NPS treatments.

Economical analysis of the first 6 years of the network shows that NPS fertilization at P and S rates equivalent to grain nutrient removal plus 10%, and highly responsive rates for N, could be profitable under the conditions of the CREA Region of Southern Santa Fe. **Figure 5** shows that the accumulated gross margin for the 6 years of C-W/S rotation was higher than the C-S-W/S rotation. This could be attributed to the lower soil Bray P-1 levels of the C-W/S sites, and increased crop P demand due to the more frequent appearance of corn and wheat in the rotation. BC

IPNI Project # ARG-12

Dr. García is Regional Director, IPNI Latin America-Southern Cone, fgarcia@ipni.net. Mr. Boxler, Mr. Minteguiaga, Mr. Pozzi, and Mr. Firpo are with the Southern Santa Fe Region of CREA, Mr. Deza Marin is with Agroservicios Pampeanos (ASP), and Mr. Berardo is with Laboratorio Fertilab-INTA-FCA Balcarce.

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Acknowledgments

We greatly acknowledge the help and collaboration of all the farmers and farm's staff who may possible this study, and the support of Agroservicios Pampeanos (ASP) since 2000.

International Plant Nutrition Institute Announces the "IPNI Science Award"

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

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

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

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

Scholar Award Recipients Named by International Plant Nutrition Institute

The first group of winners of the Scholar Awards sponsored by IPNI has been announced. The awards of US$2500 (twenty-five hundred dollars) each are conferred to deserving graduate students in sciences relevant to plant nutrition and management of crop nutrients.

The five recipients for 2007 and their universities are:

- **Miss Zhu Hongxia**, Southwest University, Chongqing, China
- **Mr. Fernando Ramos Gourcy**, Almería University, Spain
- **Mrs. Nunuk Suprihati**, Bogor Agricultural University, Indonesia
- **Mr. Christopher Boomsma**, Purdue University, West Lafayette, Indiana, U.S.A.
- **Miss K. Vanitha**, Tamil Nadu Agricultural University, Coimbatore, India

"We had a significant number of applications for these new awards in 2007 and were impressed with the quality and credentials of the graduate students," said Dr. Terry L. Roberts, IPNI President. "This speaks well of the academic institutions where these students are pursuing advanced degrees, and it is also a credit to their major professors and advisers."

Funding for the Scholar Awards is provided through support of member companies of IPNI, primarily 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 of information for each of the 2007 winners.

Zhu Hongxia

Miss Zhu Hongxia is completing her Masters of Science degree in the Department of Resources and Environment of Southwest University in Chongqing, China. Her thesis title is "Effect of Slow/Controlled Release Compound Fertilizer (SRCF) on Soil Nitrogen and Enzyme Activity", which focuses on characteristics of nutrient release of SRCF and effect on plant growth. The objective of this research is to evaluate the effect of SRCF on soil fertility and nutrient supply to plants. Several advantages have been identified related to SRCF use in crops. Miss Zhu has written two scientific papers as first author and is third author on another. For the future, she hopes to work as a teacher or researcher, with a longer-term goal of studying for a Ph.D.

Fernando Ramos Gourcy

Mr. Fernando Ramos Gourcy is pursuing studies for a Ph.D. at the University of Almería in Spain, with a thesis title of "Programation of Organic Fertilization with Mulching and Drip Irrigation Techniques." He is originally from Mexico and is currently an instructor at Universidad Autónoma de Aguascalientes (UAA) in Mexico. Mr. Ramos Gourcy received his B.S. degree in 1987 at UAA and earned his M.Sc. in 1993 at Instituto Agronómico Med. de Zaragoza in Spain. He has been very active in arranging and managing exchange programs among institutions in various countries for professors and students, while also encouraging cooperative research projects. Mr. Ramos Gourcy has visited more than 20 countries in Europe, the Middle East, Africa, and the Americas. He is familiar with the difficulties in agricultural production in less developed countries and seeks to adapt intensive and efficient production methods from more advanced areas. Mr. Ramos Gourcy has worked extensively in rural community development in Mexico and has served as a consultant to the Inter-American Development Bank.

Nunuk Suprihati

Mrs. Nunuk Suprihati is completing her Ph.D. in Soil Science and Land Resources at Bogor Agricultural University (IBP) in Bogor, Indonesia. Her thesis title is "Microbe Population, Methane and Nitrous Oxide in a Rice Field: Effect of Water Management, Organic Matter and N Fertilizer." The main goal addresses how to decrease methane and nitrous oxide fluxes from rice fields without reducing rice yield by the management of water, organic matter, and N fertilizer. Rice straw incorporation is an important means of maintaining tropical soil productivity. The project seeks to determine how straw management will impact on greenhouse gas emissions, when fertilizer N and irrigation are manipulated. Mrs. Suprihati is a native of Karanganyar in Central Java, and completed her B.S. and M.Sc. degrees at IBP. Her career goals include teaching and research work on soil management and soil fertility. She has special interest in how agricultural practices impact the environment, and how effects can be minimized.


Christopher Boomsma

Mr. Christopher Boomsma is completing his Ph.D. in Crop Physiology and Cropping Systems at Purdue University. His thesis title is "Intraspecific Competition and Plant-to-Plant Variability in Maize: Nitrogen Rate and Plant Density Effects." Research for the dissertation seeks to elucidate the physiological mechanisms in maize (corn) associated with intraspecific competition and plant-to-plant variability, and how these mechanisms are affected by varying N availability at multiple plant populations. Mr. Boomsma is a native of Illinois and completed his B.S. degree in 2003 at Dordt College in Sioux Center, Iowa. His career goals include work in either an academic or industrial setting as a research scientist in crop improvement at the interface of crop physiology and soil fertility. He is particularly interested in future research on the effects of limited versus optimum N availability on crop physiology under water-limiting conditions.


K. Vanitha

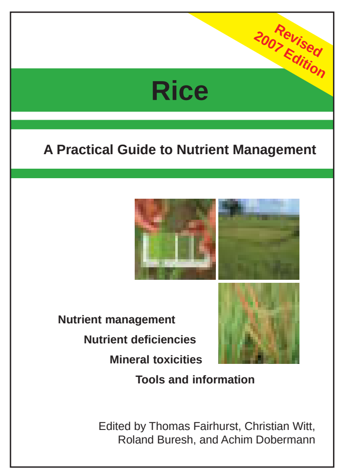
Miss K. Vanitha is a M.Sc. student in Crop Physiology at Tamil Nadu Agricultural University in India. Her thesis title is "Drip Fertigation and its Nutrio-Physiological Impact in Aerobic Rice (*Oryza sativa* L.)." Rice production and water conservation are two major factors impacting food production in India. Aerobic rice is a new concept to further decrease the water requirements in rice production, which will have major consequences for both soil and plant nutrient dynamics. The objectives of this thesis project are to: 1) evaluate the compatibility of drip-fertigation for aerobic rice culture under limited water availability, 2) to work out the production function of water and fertilizer for aerobic rice culture, 3) to standardize crop management options for enhancing aerobic rice productivity under drip-fertigation technology, and 4) to evaluate the physiological and chemical bases of performance of aerobic rice in the drip-fertigation micro-irrigation system. Miss Vanitha is a native of Bommidi in Tamil Nadu and completed her B.Sc. degree in 2006. Her career goals are to pursue a Ph.D. in abiotic stress management of crops, in particular drought tolerance.

The IPNI Scholar Award recipients are selected by a committee of scientific staff of the organization. The awards are made directly to the students 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<**. BC

Rice: A Practical Guide to Nutrient Management
Revised Edition Available for Sale and Download

In the last 5 years, site-specific nutrient management (SSNM) for rice has become an integral part of initiatives on improving nutrient management in many Asian countries. Nutrient recommendations were tailored to location-specific needs, evaluated together with rice farmers, and widely promoted through public and private partnerships. The first edition of *Rice: A Practical Guide to Nutrient Management*, published in 2002, quickly became the standard reference for printed materials on SSNM. The guide was in high demand with 2,000 copies distributed and sold to date.

Over the years, SSNM has been continually refined through research and evaluation as part of the Irrigated Rice Research Consortium. Conceptual improvements and simplifications were made particularly in N management. A standardized 4-panel leaf color chart (LCC) was produced and the promotion of the new LCC continues, with more than 250,000 units distributed to date. A new SSNM website was developed (www.irri.org/irrc/ssnm) to provide up-to-date information and local recommendations for major rice-growing areas in Asia. The revised edition of the practical guide thus became necessary to be consistent with newer information provided at the SSNM website and local training materials. This 2007 edition will be translated into a number of languages, including Bangla, Chinese, Hindi, Indonesian, and Vietnamese. The pocket-sized guide introduces the concept of yield gaps and the underlying constraints. The functions of each nutrient are explained, with a description of the deficiency symptoms and recommended strategies for improved nutrient management. The 47-page color annex provides a pictorial guide to identification of nutrient deficiencies in rice.



To make the 2nd edition of the guide as widely accessible as possible, the publishers decided not only to sell the guide through their websites and bookstores, but also to make the guide available in electronic format (pdf) at the websites of IRRI (www.irri.org) and the Southeast Asia Program of IPNI and IPI (www.ipni.net/seasia). This arrangement uses a Creative Commons "attribution-noncommercial-share alike" license: http://creativecommons.org/licenses/by-nc-sa/3.0. BC

Global Warming Potential of High-Yielding Continuous Corn and Corn-Soybean Systems

By A. Dobermann, D.T. Walters, and M.A.A. Adviento-Borbe

The global warming potential (GWP) of recommended (average) and intensive (high-yield) levels of management for both continuous corn (CC) and corn-soybean (CS) rotations was determined in this Nebraska study. Measurements included net changes in soil organic carbon (SOC), intrinsic C costs associated with crop production, and net emissions of greenhouse gases (GHG) such as N_2O and CH_4. Results indicate that intensification of cropping does not necessarily increase GHG emissions and GWP of agricultural systems provided that crops are grown with best management practices (BMPs) and near yield potential levels. In fact, high-yielding CC systems have significant potential for GHG mitigation, particularly when corn is converted to ethanol.

Meeting the future global demand for corn (maize) and soybean, including the rapidly rising feedstock demand for biofuel production, will largely have to be achieved through yield increases (Cassman et al., 2003). Average crop yields may have to approach 80% of the yield potential or more, particularly in areas with favorable rainfall or irrigation. At issue is whether such high crop yields can be achieved without increasing GHG emissions from agricultural land. A central hypothesis for such an ecological intensification of agriculture is that an optimal balance of high productivity, sustainability, and minimal environmental impact can be achieved by fine-tuning of management towards better exploitation of crop yield potential. To assess such options requires full accounting of the GWP of agricultural systems, including net changes in SOC, intrinsic C costs associated with crop production, and net emissions of GHG such as N_2O and CH_4. Such information is scarce for cropping systems that are designed to explore the upper limits of agriculture.

The Ecological Intensification Experiment

A long-term experiment on Ecological Intensification of Irrigated Maize-Based Cropping Systems was established in 1999 in Lincoln, Nebraska, USA. The primary objective of this study is to evaluate resource-efficient management concepts for achieving crop yields that approach the climatic yield potential. In this article, we summarize the net GWP of four high-yielding cropping systems. The soil at the study site is a deep Kennebec silty clay loam with relatively high soil fertility status (pH 6 to 6.5, 2.5 to 3% organic matter, 300 to 400 ppm K, and 60 to 80 ppm Bray-1 P). The field experiment was conducted with three crop rotations as main plots (CC – continuous corn, CS – corn-soybean with corn in even years, SC – corn-soybean with corn in odd years), three plant population densities as sub-plots and two levels of nutrient management as sub-subplots. Four management systems were selected for this analysis: 1) CC-rec: continuous corn with recommended management, 2) CC-int: continuous corn with intensified management, 3) CS-rec: corn-soybean rotation with recommended management, and 4) CS-int: corn-soybean rotation with intensified management.

Management practices are summarized in **Table 1**. The CC-rec and CS-rec systems represent recommended plant populations and nutrient and water management practices for growing irrigated corn and soybean in eastern Nebraska, aiming at corn yields of about 14 Mg/ha (223 bu/A). In the CC-int and CS-int systems, management aimed at corn yields of about 18 Mg/ha (287 bu/A), which is equivalent to the climatic yield potential at this site in favorable years. Key additional measures included increased plant populations, increased fertilizer rates, and more frequent N applications to achieve high N use efficiency at high input levels. In all systems, annual amounts of fertilizer-N were adjusted using an algorithm which includes yield goal, SOM content, residual NO_3-N in spring, and credits given to legumes as previous crops, manure, or N applied with irrigation water (Shapiro et al., 2003). In CC-rec and CS-rec, N fertilizer was applied pre-plant (50 to 60%) and at 6-leaf stage of corn. In CC-int and CS-int, N application to corn was done in four split applications (pre-plant, V6, V10, shortly before tasseling). Since 2001 (CC-int) or 2004 (CS-int), N management in the two intensive systems included an additional N application of 50 kg/ha (45 lb/A) on the corn residue before plowing in fall to facilitate better decomposition and humification of corn residue. Nitrogen rates of the succeeding crop were adjusted accordingly. Under soybean, N fertilizer was applied only in the CS-int system at R3.5 stage. Due to high soil test levels, no P and K fertilizer was applied in CC-rec and CS-rec, but corn and soybean grown in CC-int and CS-int received annual applications of P and K to replenish crop removal.

Soil surface fluxes of CO_2, N_2O, and CH_4 and associated environmental variables were measured weekly to bi-weekly during the 2003 to 2005 growing seasons using a portable photoacoustic spectrometer. Changes in SOC and total soil N (TSN) in the top 0.3 m (1 ft.) were measured by collecting soil samples in June of 2000 and 2005. Total SOC and TSN stocks were calculated for a dry soil mass of about 0.3 m depth as described by Gifford and Roderick (2003). Grain yields of corn (15.5% moisture) and soybean (13% moisture) as well as crop N and C uptake in different plant parts were determined annually. Calculation of net GWP followed Robertson and Grace (2004) and included intrinsic C costs associated with all production inputs and field operations, measured changes in SOC, and measured fluxes of N_2O and CH_4.

Crop Yields and Crop Residues

Abbreviations and notes for this article: C = carbon; CO_2 = carbon dioxide; ppm = parts per million; N = nitrogen; N_2O = nitrous oxide; CH_4 = methane; SOM = soil organic matter; NO_3^- = nitrate.

Table 1. Crop management practices, grain yields, and crop residue input in continuous maize (CC) and maize-soybean (CS) systems with recommended (-rec) or intensive management (-int).

	CC-rec	CC-int	CS-rec[1]	CS-int[1]
Plant population, plants/m^2	7-9	9-11	7-9 (C);25-28 (S)	9-11 (C); 28-35 (S)
Row spacing, m	0.76	0.76	0.76	0.76 (C); 0.38 or 0.76 (S)
Annual N application, kg N/ha	180-240	250-310	130-140 (C); 0 (S)	230-250 (C); 80-130 (S)
N applications during growing season	2	4	2 (C); 0 (S)	4 (C); 1 (S)
N application on maize residue in fall	None	since 2001	None	since 2004
Annual P application, kg P/ha	0	45	0	45
Annual K application, kg K/ha	0	85	0	85
Long-term averages, 2000-2005:				
Annual fertilizer N input, kg N/ha	201	299	70	172
Annual total crop N uptake, kg N/ha	260	317	324	346
Annual N removal with grain, kg N/ha	176	194	229	238
Grain yield of corn, Mg/ha	13.95	14.95	14.71	15.61
Grain yield of soybean, Mg/ha	–	–	4.89	5.02

[1]C and S indicate corn and soybean crops, respectively.

levels of management intensity. Within each crop rotation, however, intensified management did not cause a significant increase in CO_2 emissions as compared to the recommended practice. Hence, increasing crop productivity is a key measure for increasing the soil C sequestration potential.

Both SOC and TSN increased in the two CC systems, but decreased in CS-rec or remained unchanged in CS-int (**Figure 2b**). On average, SOC declined at an annual rate of 300 kg C/ha/yr in CS-rec, whereas it increased at a rate of 620 kg C/ha/yr in CC-int. Similar trends were observed for TSN. The different changes in SOC and TSN largely reflected the differences in crop residue amounts and composition (**Figure 2a**). In the intensive continuous corn systems, incorporation of large amounts of residue C and N has led to a significant build-up of SOM over a few years. Although corn yields and N use efficiency were highest in the intensive corn-soybean system (**Table 1**), this excellent performance was achieved at the cost of exploiting soil C and N reserves.

Our results confirm those of recent eddy covariance studies at other sites, showing that significant net C losses during the soybean phase limit the soil C sequestration potential in corn-soybean rotations of North America (Baker and Griffis, 2005; Verma et al., 2005). Large grain N removal, less residue input, and rapid cycling of soybean residue through young organic matter fractions were observed in the CS rotation, leading us to conclude that the N-credit attributed to corn-soybean rotations

Average crop yields in this long-term experiment (**Table 1**) were close to the yield potential of soybean and corn at the location and significantly higher than national or state averages. Corn yields were generally in the 13.5 to 18 Mg/ha (215 to 287 bu/A) range or within 84 to 97% of the simulated yield potential. Corn following soybean (CS) yielded about 5 to 11% higher than continuous corn (CC), primarily due to fewer problems with crop establishment and some insect pests. Soybean yields averaged about 5 Mg/ha (74 bu/A), with a maximum yield of 5.9 Mg/ha (88 bu/A) measured in 2001. Nitrogen use efficiency in corn grown in 2003-2004, calculated as amount of grain produced per kg N applied, increased in the order CC-int (62) < CS-int < CC-rec < CS-rec (123 kg/kg), which is significantly higher than national averages of about 58 to 60 kg/kg achieved in recent years.

Since the start of this experiment in 1999, large amounts of crop residue have been returned to the soil in all four management systems, but with significant differences among them in terms of dry matter amounts and composition (**Figure 1**). Corn returned 75 to 100% more residue than soybean, but with a much wider C/N ratio. On a whole crop rotation basis, average annual C return with above-ground residue increased in the order CS-rec < CS-int (+8%) < CC-rec (+22%) < CC-int (+39%), whereas residue N inputs followed the order CC-rec < CS-rec < CS-int < CC-int (**Figure 2a**). Both residue C and N input were highest in the CC-int system, exceeding the more commonly practiced CS-rec system by 30 to 40%.

Changes in SOC

Despite the large biomass production in our high-yielding maize systems, peak growing season (about 40 to 60 kg/ha/day) or annual (4,300 to 10,200 kg C/ha/yr) soil CO_2 efflux was within typical ranges for arable crops. In a complete 2-year crop rotation with flux measurements conducted in corn and soybean (2004 – 2005), soil CO_2 efflux in the continuous corn systems was 22% larger than in corn-soybean rotations at both

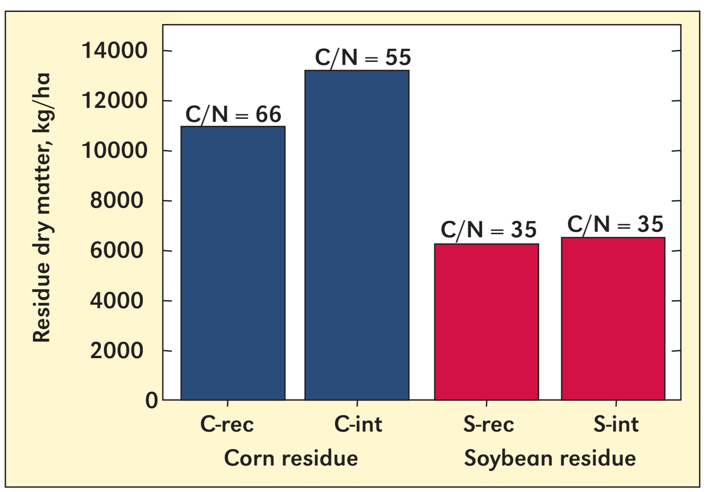


Figure 1. Average annual input of crop residues in recommended (-rec) and intensively managed (-int) systems at Lincoln, Nebraska.

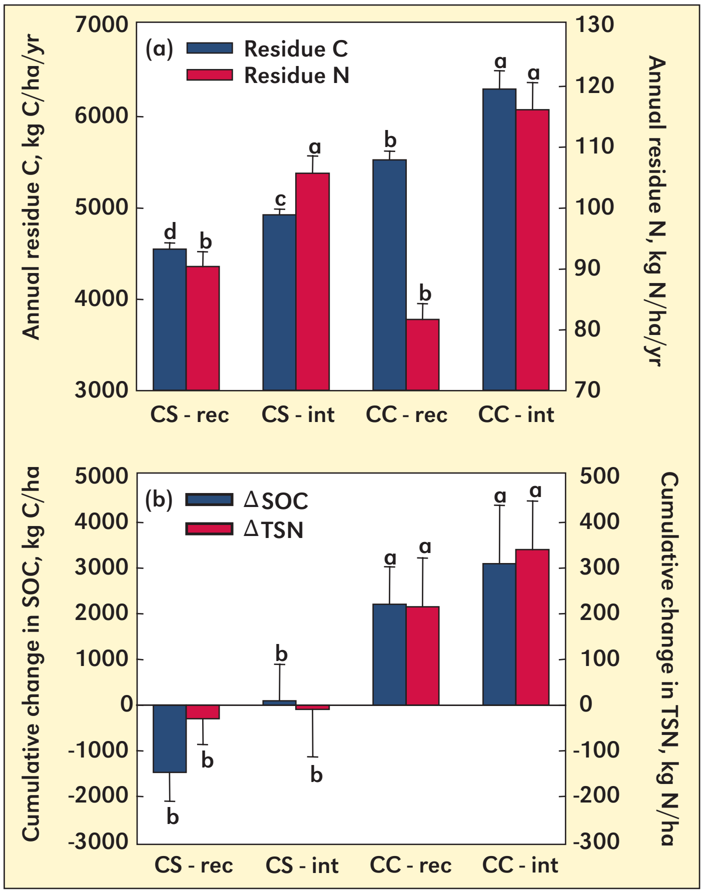


Figure 2. Average annual input of C and N with aboveground crop residues during 1999-2004 (a) and changes in soil organic C (SOC) and total soil N (TSN) for the corresponding period (b) in continuous maize (CC) and maize-soybean (CS) systems at Lincoln, Nebraska. Means and standard errors of two population densities for each management system. Letters indicate statistical significance ($p<0.05$) of treatment differences (Holm-Sidak test).

appears to be due to "mining" of soil N reserves. Soybean has the effect of temporarily storing more N and labile C in the light and mobile humic acid fractions of SOM, which is then lost in the corn year due to mineralization to satisfy crop N demand. Under intensive management with very high crop N demand, this can result in a net decline of soil C and N over time.

Significant potential for sequestration of atmospheric C exists in intensively managed continuous corn systems. In CC-int, 14% more crop residue C was returned to the soil than in CC-rec, but there was no significant difference in soil CO_2 fluxes. Likewise, residue C amounts in CC-int were 28 to 39% larger than in the two corn-soybean systems, but the soil CO_2 efflux increase was only about 20%. Conditions for humification and accumulation of C and N in more recalcitrant SOM fractions appear to be more favorable in continuous corn systems, particularly when residue is incorporated in the soil and sufficient N is available to support the humification process. Applying N fertilizer in fall on corn residue followed by relatively deep but non-inverting incorporation probably enhanced the formation of more stable humus compounds resulting from residue decomposition during the fall to spring period. This seems to contradict the widespread notion that conservation tillage is required for sequestering atmospheric CO_2 in agricultural soils. Recent studies suggest, however, that when sampling is done deep enough and SOC stocks are properly expressed on an equivalent soil dry mass basis, the potential for no-till systems to sequester atmospheric CO_2 in SOC seems limited (VandenBygaart and Angers, 2006; Baker et al., 2007). Particularly in high-yielding systems with large amounts of crop residue, no-till cropping is not necessarily the best management strategy because of high CO_2 respiration losses from the soil surface (Verma et al., 2005).

Global Warming Potential

With conventional use of corn and soybean grain, all four cropping systems where net sources of GHG, with GWP ranging from 540 to 1,020 kg CO_2-C/ha/yr (**Table 2**). Positive or negative changes in SOC, intrinsic C costs associated with crop production and soil N_2O emissions were major contributors to the net GWP, whereas CH_4 oxidation added only little mitigation capacity. Nitrogen fertilizer (16 to 36%), energy used for irrigation (15 to 22%), electricity for grain drying (13 to 18%), diesel (10 to 16%), and lime (9 to 13%) were the major components of the C costs associated with the agricultural production. Despite higher C cost associated with crop production and also higher N_2O emissions, net GWP in continuous maize systems was lower than that of the corn-soybean systems because sequestration of atmospheric CO_2 in SOC was observed in both CC systems (**Table 2**). Within each crop rotation, intensification of management practices increased production C costs and also N_2O emissions, but when combined with the net change in SOC resulted in only slightly higher GWP for CC-int as compared to CC-rec or no change in GWP for CS-int as compared to CS-rec.

Large variations in N_2O emissions among years caused, however, large inter-annual variation in the GWP of these systems. In the CC-rec system, annual N_2O emissions during 2003 to 2005 ranged from 1.28 to 3.92 kg N_2O-N/A, which is equivalent to a GWP range of 320 kg CO_2-C/ha/yr. In the CC-int system, annual N_2O emissions ranged from a low of 1.8 kg N_2O-N/ha in 2005 to a high of 9.24 kg N_2O-N/ha in 2003, or a GWP range of 94 kg CO_2-C/ha/yr. Seasonal variations in soil CO_2 and N_2O fluxes were principally dependent upon temperature, soil water status associated with precipitation and irrigation events, crop growth, and, to a lesser extent soil NO_3-N content. Although the amount of fertilizer N applied to corn grown in the intensive cropping systems was 40% (CC) or 64 to 92% (CS) greater than in the recommended cropping systems, N_2O losses were not directly related to the level of N input only. This contradicts the assumptions made in the current IPCC method, which calculates the contributions of N fertilizer to global anthropogenic N_2O fluxes by assuming that on average 1.25±1% of the N amount applied is lost as N_2O (IPCC, 2001). In our study, N_2O emissions from N fertilizer applied to corn ranged from 1.9 to 3.5% in 2003, 0.8 to 1.5% in 2004, and 0.4 to 0.5% in 2005, with no consistent differences among the four systems. Low N_2O fluxes in 2004 and 2005 illustrated the potential to reduce N_2O emissions from intensively managed agricultural systems.

Table 2. Estimated net global warming potential (GWP) in corn-based cropping systems with recommended and intensive management.

GWP components		Continuous corn (CC) Recomm.	Continuous corn (CC) Intensive	Corn-soybean (CS) Recomm.	Corn-soybean (CS) Intensive
		------------ kg CO_2-C equivalents/ha/yr ------------			
Agricultural Production[1]	N fertilizer	220	330	80	180
	P, K, fertilizer	0	60	0	60
	Lime	60	90	60	90
	Seed, pesticides	50	60	50	60
	Machinery, transport	20	30	20	30
	Diesel	90	90	80	80
	Irrigation	140	140	110	110
	Grain drying	110	120	90	100
	Total	690	920	490	710
Δ Soil C[2]		-440	-620	300	-20
Soil N_2O[3]		320	570	250	340
Soil CH_4[3]		-30	-30	-20	-10
GWP[4]		540	840	1,020	1,020

[1] Carbon cost associated with crop production. Average for corn and soybean crops grown during 2000-2005.
[2] Average annual change in SOC, based on measurements of SOC conducted in June 2000 and June 2005.
[3] Radiative forcing potential for 100 year time frame. CC systems: average of three corn crops (2003-2005); CS systems: weighted average of two corn crops (2003-2004) and one soybean crop (2005).
[4] GWP = Agricultural production + ΔSOC + soil N_2O + soil CH_4.

Reduced N_2O losses may not be the only or most important environmental consequence. Direct measurements of NO_3 leaching and its impact on water quality were beyond the scope of our study, but it is likely that the management practices employed resulted in both reduced N_2O and NO_3 leaching losses. BC

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Funding for this project was provided by IPNI, FAR, the Fluid Fertilizer Foundation (FFF), and the U.S. Department of Energy, EPSCoR program.

IPNI/FAR Project #NE-11F

Conclusions

Intensification of cropping does not necessarily increase GHG emissions and GWP of agricultural systems provided that crops are grown with best management practices and near yield potential levels, resulting in high resource use efficiency. High-yielding continuous corn systems have significant potential for GHG mitigation, particularly when corn is converted to bio-ethanol. Managing a crop at high yield levels creates large sinks for CO_2 and mineral N, thereby providing the pre-requisite for sequestering atmospheric CO_2 and avoiding large N_2O emissions that could results from inefficient utilization of soil or fertilizer N.

Major components for improving crop management to reduce GWP are (i) choosing the right combination of adopted varieties, planting date and plant population to maximize yield potential, crop biomass productivity and residue input, (ii) tactical water and N management decisions that minimize energy use, achieve high N use efficiency and avoid high N_2O emissions, and (iii) a tillage and residue management approach that can handle the large amounts of residue produced and favors the build-up of SOM.

Policies that favor greater adoption of such management practices would not only satisfy the increasing demands for crops such as corn and soybean, but may also mitigate GHG emissions from agriculture. Future research should concentrate on demonstrating the potential impact of such management practices at production scale, particularly to determine whether it is possible to reduce the large seasonal fluctuations in N_2O and CO_2 emissions from the soil surface.

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The Delta Yield Concept: An Update

By T.S. Murrell

Delta yield is the measure of crop response. Relating it to fertilizer need may improve fertilizer recommendations in the future by incorporating both yield level and crop responsiveness.

In 1996, an article appeared in *Better Crops with Plant Food*, written by Dr. R.G. Kachanoski, that introduced the delta yield concept to readers of this magazine (Kachanoski, 1996b). The question being addressed at that time was whether or not yield maps provided a reasonable basis upon which to vary N application across the field, since many N recommendations were based on estimates of attainable yield.

In the original article, it was shown that economically optimum N rates (EONR) were poorly correlated to maximum yield or the yield associated with EONR. Since that time, other studies have noted similar results, such as those in a regional publication by Sawyer et al. (2006).

So why this lack of a relationship between EONR and the yield at EONR? **Figure 1** provides some possible reasons. The figure shows three possible responses of corn to applied N, holding maximum yield constant. The lowest curve illustrates a very large response to applied N. This type of response often results when the soil itself is not capable of supplying much N, indicated by a low yield without applied N and a high EONR. At the other end of the spectrum is the straight line across the top, showing no response to applied N and an EONR of zero. In this case, the soil supply is adequate, making subsequent additions unnecessary. The curve in the middle shows a case between these two extremes, where soil supplies of N and EONR are moderate. In each case, the final yield is the same, but the EONRs needed to attain that yield are very different. So rather than maximum yield or yield at EONR, it is the response to N that is better related to EONR – the concept proposed by Kachanoski (Kachanoski et al., 1996a; Kachanoski et al., 1996b).

The metric Kachanoski used to describe yield response was delta yield (ΔYield). The Greek letter delta (Δ) is often used as shorthand notation for "the difference in" or "the change in" some parameter. So delta yield is simply an abbreviated way of saying the difference in yield. As illustrated in **Figure 2**, this difference was between the yield where no N was applied and either 1) the maximum yield (ΔYield-max) or 2) the yield associated with EONR (ΔYield-econ). ΔYield-econ is illustrated in **Figure 2**.

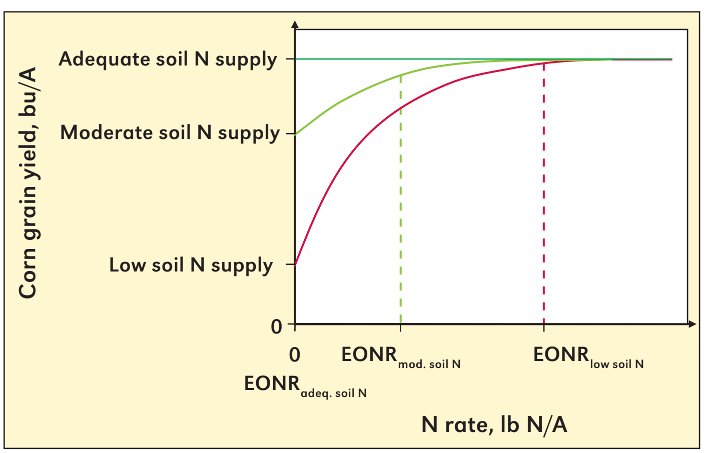

Figure 1. Conceptual responses of corn to applied N at different soil N supplies. Maximum yield is held constant for all responses.

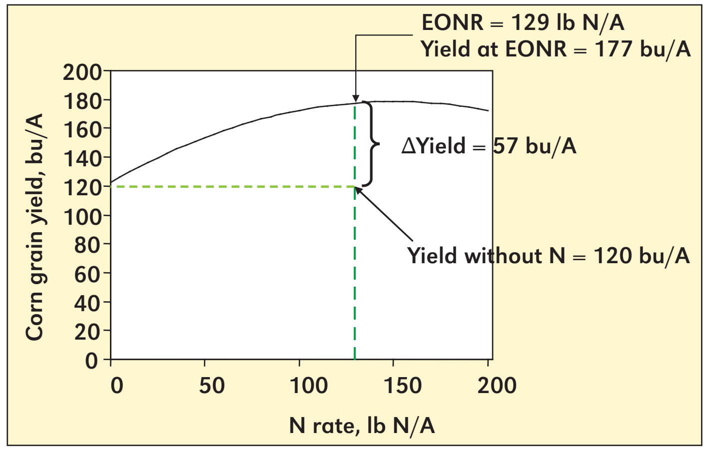

Figure 2. An example of corn response to applied N. Delta yield is the difference between the yield without applied N and either the maximum yield or the yield at EONR. The latter definition is illustrated

In the past few years in the Corn Belt, scientists have been revisiting the validity of current recommendations that are based on yield goals and N credits. Dr. Paul Fixen, IPNI, recently wrote a retrospective of how such recommendations came into being and the requirements for their future use (Fixen, 2006). Recent work by many scientists at land grant universities has centered on creating recommendations from generalized N response curves. Such recommendations do not consider yield goals due to their lack of correlation with EONR (Sawyer et al., 2006).

Kachanoski noted that ΔYield-econ and EONR were well related. ΔYield-econ accounted for 50 to 75% of the variability in EONR in his studies (Kachanoski et al., 1996b). More recently, Lory and Sharf (2003) examined 298 N response experiments across five state (Illinois, Minnesota, Missouri, Pennsylvania, and Wisconsin). In 105 of the 298 locations, EONR was zero, reflecting the lack of responsiveness to any applied N at those sites. At the 193 remaining responsive sites, ΔYield-econ accounted for approximately 47% of the variability in EONR, when all data were grouped together. When such relationships were separated out by each state, the range in EONR variability accounted for by ΔYield-econ was 35 to 65%.

Fairly good relationships between delta yield and EONR led Lory and Sharf to propose a generalized approach to making

Abbreviations and notes for this article: N = nitrogen; EONR = economically optimum N rate; ISNT = Illinois Soil Nitrogen Test.

fertilizer N recommendations. Recommended N was expressed as a function of the yield without N, delta yield, and the change in grain N concentration with delta yield. This approach to making recommendations represented a fundamental shift away from using approaches based primarily upon yield goal. However, yield was still an important component and determined N requirements through both the yield without N and the delta yield factors in the equation.

The Future

The new generalized model for making recommendations proposed by Lory and Scharf creates fundamentally new types of information that must be collected on the farm if crop advisers wish to tailor such equations to fit their local conditions. Rather than just keeping records of historical yields, information will need to be gathered on the yields attainable when no N is applied as well as the magnitude of crop response to applied N, both in grain yield and in grain N concentration. Lory and Scharf determined, using economics current at the writing of their paper, that collecting data on yield without N, which also provides the basis for calculating delta yield, would cost less than $1.38/A if the strip were 60 ft. by 120 ft. and placed once every 10 A in the field. As Blackmer and White noted, with the advent of newer technologies, such information is much more readily collected now than in the past (Blackmer and White, 1998). However, university scientists and advisers will need to work together to develop protocols to collect, share, analyze, and interpret data.

In the ΔYield concept, yield without N is a biological indication of a soil's ability to supply N to the crop. Ongoing research has been conducted to develop soil tests that are able to indicate soil N supply. A newer example is the Illinois Soil Nitrogen Test (ISNT) (Khan et al., 2001). If such tests can be calibrated, they may be able to substitute for information gained from on-farm experiments. Williams et al. (2007) investigated several soil N tests, including ISNT, delta yield, and EONR relationships. **Figure 3a** shows the relationship between ΔYield-max and EONR for the mineral soils in their study, and is similar to the types of results obtained by Lory and Scharf (2003), with ΔYield accounting for 43% of the variability in EONR. **Figure 3b** demonstrates that ISNT was related to ΔYield and accounted for 49% of its variability, making it possible to relate ISNT to EONR, as shown in **Figure 3c**. This latter graph shows ISNT accounted for 90% of the variability in EONR on the mineral soils studied. Williams et al. state that much work remains to calibrate ISNT to crop response. Other studies have shown difficulties in relating ISNT with crop response when no other factors were considered (Klapwyk and Ketterings, 2006). In the future, soil tests or some other methods of detection may alleviate the need to conduct on-farm research to estimate delta yield measurements to further investigate their efficacy of use. BC

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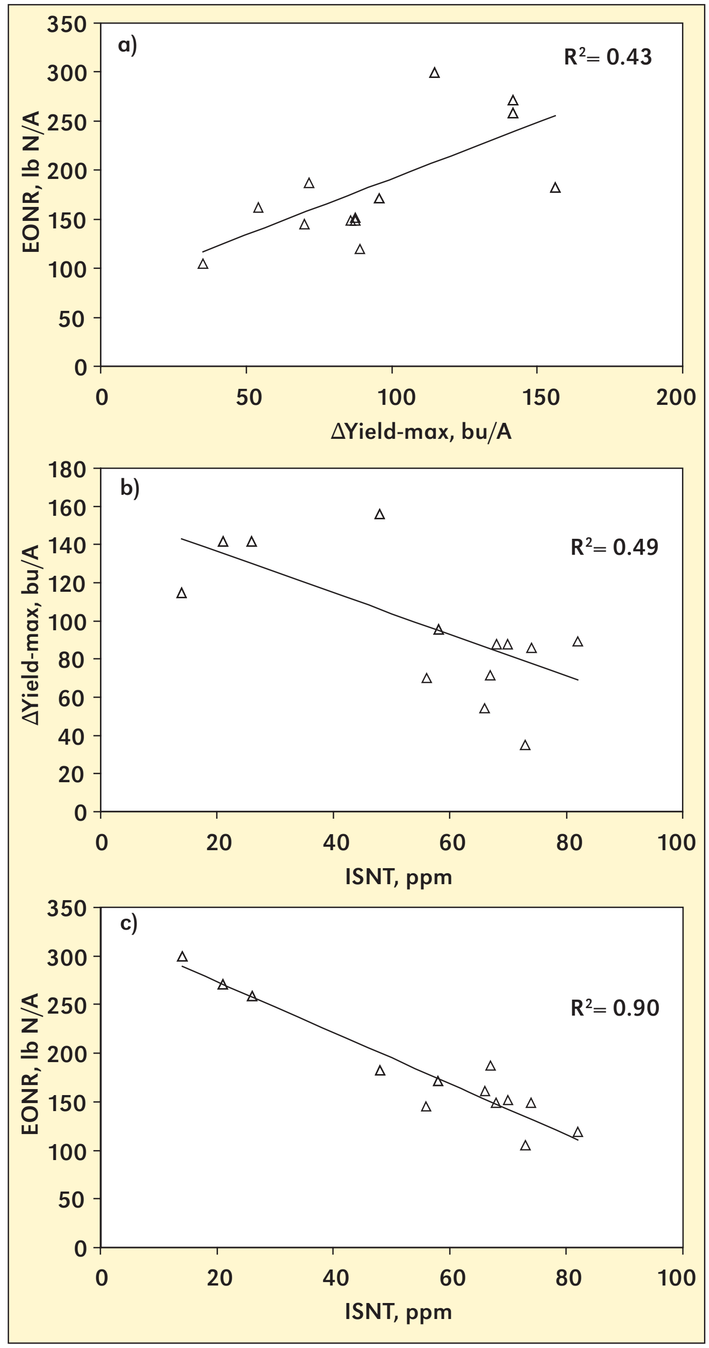

Figure 3. An example of how the delta yield concept is used when interpreting research results: a) a relationship showing that as responsiveness increases, optimum N rates increase; b) an example of how a soil N test might substitute for an actual measurement of delta yield; and c) an example showing how a soil N test might be able to predict EONR (adapted from Williams et al., 2007).

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Maximizing Yield, Nutrient Use Efficiency, and Profit in Summer Black Gram

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

Nutrient demand analysis helps to identify the most profitable response to fertilizer applied to a largely neglected but particularly important pulse crop production system in northcentral India.

Uttar Pradesh is the most agriculturally important state in India with respect to staple food production. Because the majority of the population is vegetarian, pulses represent the major source of protein and assume great importance for food, nutrition, and agriculture sustainability. Black gram is a prominent rainy and summer season pulse crop presently occupying 492,000 ha in Uttar Pradesh. Average productivity is low at 429 kg/ha. Among the various factors influencing black gram yield, balanced use of plant nutrients is most critical. Inadequate and unbalanced use of fertilizers has resulted in large-scale multi-nutrient deficiencies which are spreading in space and time.

Fertilizer use in both rainy and summer season pulse crops is altogether missing, leading to poor crop yields. Presently, fertilizer use in the state is confined to rice, wheat, and other important crops such as sugarcane, potato, and oilseeds. In view of the fact that per capita per day availability of pulses in India is currently on the decline, it is important to evaluate the effect of adequate and balanced fertilization on maximizing yield and farmer profits with black gram.

A field experiment was conducted at the Fertilizer Research Station of Chandra Sekhar Azad University of Agriculture and Technology in Pura, Uttar Pradesh, during the summer season (March to June) of 2005. The site is located within the central plain zone of Uttar Pradesh, which has the largest area under pulse crops in India. The site had a sandy loam soil, pH 8.0, and 0.4% organic carbon. Available N (alkaline permanganate method) and P (Olsen) were low, and available K (ammonium acetate extractable) was medium. Fourteen treatments were formulated and tested based on need to improve the state recommendation (SR) for N, P, and K with and without secondary and micronutrients (**Table 1**). The experiment was laid out in a randomized block design with four replications. Urea, DAP, and KCl were used as N, P, and K fertilizer sources. All fertilizers were applied basally. Black gram variety "Type 9" was sown on March 25 and harvested at full maturity on June 23. The recommended package of agronomic practices was adopted including practical management of weeds and timely irrigation to avoid moisture stress.

A maximum seed yield of 1,254 kg/ha was obtained under T_9 (complete). Yield under T_9 was 123% above the control (**Table 1**). Treatments supplying less N (T_8) or no Zn (T_{11}) provided yields that were statistically equivalent to T_9. Stover yield followed a similar trend and varied between 1,068 kg/ha in the control to 2,006 kg/ha under T_9. Net returns for the most profitable treatments followed yield trends. Thus, a highest net return of Rs.9,480/ha was recorded for T_9, followed by T_8 at Rs.8,864 and T_{11} at Rs.8,795. Grain yield obtained under the control was 562 kg/ha, still above the state average, while the SR and STR produced 972 and 894 kg/ha, respectively. The lowest return above the control was obtained by omitting both P and K. Yield responded linearly to successive increases in K application rate. Yields at 0, 20, 40, and 60 kg K_2O/ha were 70, 80, 98, and 103% above the zero K control (T_3). Paired comparisons of treatments with and without B, Zn, and S demonstrated 7%, 4%, and 13% increases, respectively.

Crop response to balanced application of fertilizer was evident in plant nutrient uptake data (**Table 2**). Successive increases in K application rate enhanced N uptake by 2 to 20%, P uptake

Table 1. Effect of treatments on yield, seed response, and net return (Rs./ha) in black gram.

Treatments, kg/ha	Yield, kg/ha		Seed response over control, %	Net return[2] over control, Rs./ha
	Seed	Stover		
$T_1\ N_0P_0K_0$ (Control)	562	1,068	-	-
$T_2\ N_{15}P_0K_0S_{20}Zn_{15}B_5$	713	1,419	27	2,069
$T_3\ N_{15}P_{40}K_0S_{20}Zn_{15}B_5$	955	1,776	70	5,384
$T_4\ N_{15}P_{40}K_{20}S_{20}Zn_{15}B_5$	1,012	1,768	80	6,165
$T_5\ N_{15}P_0K_{40}S_{20}Zn_{15}B_5$	894	1,520	59	4,548
$T_6\ N_{15}P_{40}K_{40}S_{20}Zn_{15}B_5$	1114	1,938	98	7,562
$T_7\ N_{15}P_{40}K_{60}S_{20}Zn_{15}B_5$	1142	1,900	103	7,946
$T_8\ N_{15}P_{60}K_{60}S_{20}Zn_{15}B_5$	1,209	1,990	115	8,864
$T_9\ N_{22}P_{60}K_{60}S_{20}Zn_{15}B_5$ (Complete)	1,254	2,006	123	9,480
$T_{10}\ N_{22}P_{60}K_{60}S_{20}Zn_{15}B_0$	1,170	1,925	108	8,330
$T_{11}\ N_{22}P_{60}K_{60}S_{20}Zn_0B_5$	1,204	1,980	114	8,795
$T_{12}\ N_{22}P_{60}K_{60}S_0Zn_{15}B_5$	1,106	1,880	97	7,453
$T_{13}\ N_{15}P_{40}K_0S_{20}$ (SR)	972	1,790	73	5,617
$T_{14}\ N_{15}P_{15}K_{15}S_{20}$ (STR)	894	1,600	59	4,548
C.D.[1] 5%	80	119		

[1]Critical difference; [2]1US$ = 40.45 India rupees

Abbreviations and notes for this article: N = nitrogen; P = phosphorus; K = potassium; DAP = diammonium phosphate; KCl = potassium chloride; S = sulfur; B = boron; Zn = zinc.

by 5 to 22%, and K uptake by 8 to 33% compared to the control (**Table 2**). Consistent improvements in macronutrient uptake were also observed in treatments providing P, S, B, Zn, and additional N. As was observed with yield, maximum uptake for N, P, and K was achieved under the complete treatment.

Plant partitioning of nutrients between the seed and stover provides insight into the range of macronutrient removal that can be expected from black gram. Similar quantities of N and K are being exported in the form of harvested grain. On average, seed N represented 59% of total N uptake. Seed accumulation of N ranged from 18.0 to 44.6 kg/ha, whereas stover N varied from 13.7 to 30.1 kg/ha. Nitrogen concentrations in seed ranged between 3.20% (control) to 3.56% (complete), and stover N varied from 1.28% (control) to 1.50% (complete). Seed accumulation of K represented 72% of total uptake and ranged from 15.8 to 46.0 kg/ha. Stover K varied from 6.0 to 18.5 kg/ha. Seed K concentration varied from 2.82% (control) to 3.67% (complete), and stover K varied from 0.56% (control) to 0.92% (complete). Plant P was nearly equally distributed between the seed and stover as uptake ranged between 1.6 to 5.0 kg/ha within the seed and 1.6 to 4.2 kg/ha within the stover. Seed P content varied from 0.28% (control) to 0.40% (complete), whereas stover P varied from 0.15 (control) to 0.21% (complete).

The protein-rich nature of pulse crops means that these crops remove more nutrients per unit of harvested grain than cereals. Despite this, the gap between this demand and the amount of nutrients supplied to pulses is wide. Fertilizer, organic, or bio-fertilizer input is practically negligible. Evidence from this research indicates that pulse crops are quite responsive to the application of nutrients, and this is contrary to the common belief among farmers that pulses can be sustained with minimal nutrient input. Thus far, the emphasis for fertilizer use in pulses has been mainly focused on P, or N and P. In the present era of multi-nutrient deficiencies, application of K along with N and P and inclusion of secondary and micronutrients such as S, Zn, and B assumes great importance. Ample production and recycling of pulse biomass, for example after picking the pods of black gram, would also help increase soil fertility by adding biologically fixed N and improving the availability of indigenous soil nutrients.

As both area and production have been stagnating over the years, the per capita availability of pulses has declined from 61 g/day in 1950 to 30 g/day in 2000, reflecting large and uninterrupted growth in population. Affordability for this protein rich commodity has also declined due to market forces. India continues to be a net importer of pulses to meet its rising demand. India's pulse demand is estimated to reach 30 M t by 2012 – 17 to 18 M t more than current production.

Summary

Almost all types of pulse crops are grown throughout the year over three seasons in northcentral India: rainy/kharif (June to September), winter/rabi (October to March), and summer/zaid (March to June). This research achieved greater than 120% more grain productivity compared to the average summer season crop yield, plus a vast improvement in crop biomass production. On average, the additional cost of fertilizers over common practice would be Rs.1,730/ha. If such balanced fertilization were practiced in a phased manner, starting with one-quarter on the planted area in Uttar Pradesh, a net profit of Rs.9,480/ha would translate into a Rs.1.25 billion (US$30 million) cash infusion.

A strong educational effort is required by all agencies involved in improving crop productivity in India. Ensured availability of inputs through the supply chain will secure success. Government will power and policy would be most important for real adoption of adequate and balanced fertilization within the extensive pulse-growing areas. BC

Table 2. Effect of nutrient application rate on plant uptake in black gram.

	N		P		K		N+P+K	
K rate	Uptake, kg/ha	% increase	Uptake, kg/ha	% increase	Uptake, kg/ha	% increase	Uptake, kg/ha	% increase
K_0	55.7	–	5.9	–	41.1	–	102.7	–
K_{20}	57.1	2.5	6.2	5.1	44.3	7.8	107.6	4.8
K_{40}	65.8	18.1	6.8	15.2	51.8	26.0	124.4	21.1
K_{60}	66.6	19.6	7.2	22.0	54.7	33.1	128.5	25.3
P rate								
P_0	51.6	–	5.0	–	39.5	–	96.1	–
P_{40}	65.8	27.5	6.8	36.0	51.8	31.1	124.4	29.4
B rate								
B_0	69.1	–	8.0	–	57.5	–	134.6	–
B_5	74.7	8.1	9.2	15.0	64.5	12.2	148.4	10.2
Zn rate								
Zn_0	77.8	–	7.8	–	59.5	–	139.1	–
Zn_{15}	74.7	4.0	9.2	18.0	64.5	8.4	148.4	6.7
S rate								
S_0	65.7	–	7.7	–	54.5	–	127.9	–
S_{20}	74.7	13.7	9.2	19.5	64.5	18.4	148.4	16.0
N rate								
N_{15}	70.4	–	8.1	–	61.3	–	139.8	–
N_{22}	74.7	6.1	9.2	14.0	64.5	5.2	148.4	6.2

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Investigation of Soil Fertility in Citrus Orchards of Southern China

By Fang Chen, Jianwei Lu, and Dongbi Liu

A recent comprehensive analysis defines complete soil fertility profiles for mandarin and navel orange orchards based on orchard productivity.

Citrus fruit production comprises the largest fruit sector in southern China. However, most citrus orchards in China are located on poor soils and newly reclaimed lands (Zhuang, 1994; He, 1999). The potential for these orchards to alleviate poverty in marginal farming areas is well appreciated, but low yields and poor fruit quality are major hurdles to overcome for a large number of production areas. Poor soil fertility and substandard management are to blame. Poor fertilization strategies are largely a result of insufficient information on the soil fertility status in these areas.

Past research has been mainly focused on relatively small areas and/or based on a single nutrient or selected macronutrients such as N or P. Some examples of citrus soil nutrient evaluation standards do exist based on local conditions (Yue, 1990; Xie et al., 2001; Yu, 1985; Zhang, 1996; Zhang, 1990; Achituv and Akiva, 1973; Alva and Paramasivam, 1998).

The group of "brand-name" citrus in China mainly includes satsuma mandarin (*Citrus unshiu*), navel orange (*C. sinensis* L.), and "Ponkan" mandarin (*C. reticulata* Blanco). They are mainly planted on red soil in hilly regions. Some orchards are located on old river beds and sea beaches, and others are planted in flood plain soils and paddy fields. Soil pH, OM content, and soil physical properties are all important factors to be managed. Soil nutrient deficiencies, including P, K, Mg, Zn, B, and Fe are also widespread (Qin et al., 1986; Li et al., 1997; Lu et al., 2001; 2002). One of the major efforts towards improving citrus yield and quality is the identification and correction of critical soil fertility factors. This paper outlines a major citrus soil fertility investigation involving the six prominent brand-name citrus production provinces in southern China.

A total of 63 soil samples were taken from citrus orchards in 17 counties of six provinces (Hunan, Hubei, Sichuan, Jiangxi, Zhejiang, and Guangdong) during 2000 to 2001. In each county, samples were taken from several orchards considered to be low yielding (<22,500 kg/ha), mid-yielding (22,500 to 45,000 kg/ha), and high yielding (>45,000 kg/ha). Each soil sample was comprised of 20 subsoil samples taken from under the crown of citrus trees at a 0 to 30 cm depth. Soil pH, OM, total soil N, P, K, non-exchangeable K, available N, P, K, S, Ca, Mg, Si, Na, Al, Fe, Mn, Zn, B, Mo, base saturation percentage, and soil physical properties were determined. Standards for the classification of citrus soil nutrient status refer to the commonly reported standards shown in **Table 1** (Lu et al., 2002).

Soil pH for the group of orchards ranged between 3.9 and 8.9 with most being below 6.5. Usually, the optimum soil pH for citrus exists between 5.5 and 6.5, although citrus can be successfully planted in a wider pH range. Earlier results from the authors indicate that sites with initial pH values under 6.5 will show yield responses to soil amendments, causing an upward shift in soil pH. The average soil pH in high and mid-yielding orchards was 5.9, and was 5.4 in low yielding orchards (**Table 2**). In high yield orchards, 45% of soils had low to extremely low pH values under 5.5, while mid and low yielding orchards had 50% and 68% of soils under pH 5.5, respectively.

Soil OM is often used as an indicator of soil fertility for citrus orchards as yields tend to increase along with OM content. However, some believe that low OM soils, even as low as 10 g/kg, can also produce high yields with rational fertilizer application. Orchards in this study had an average OM content of 15.6 g/kg (range = 2 to 54.9 g/kg). Over 50% of orchard soils had OM contents less than 15 g/kg. Average OM for high yielding orchards was 18.2 g/kg, while mid and low yielding orchards had OM contents of 16.0 and 16.1 g/kg, respectively (**Table 2**).

Trends for total and available N, P, K, and non-exchangeable K all showed declining levels between high and low yielding orchards (**Table 2**). Using established standards, 68% of orchards were below the critical value for available N, 60% for available P, and 44% for available K. In the absence of published fertility classification standards, this research suggests 1.5 g total N/kg, 0.6 g total P/kg, 15 g total K/kg, and 300 mg non-exchangeable K/kg as tentative critical values. If considered, 92% of

Table 1. Established standards for soil fertility classification and nutrient status of citrus orchards, southern China.

Items	Extreme low	Low	Optimum	High	Extreme high
pH	<4.8	4.8-5.5	5.5-6.5	6.5-8.5	>8.5
OM, g/kg	<5	5-15	15-30	>30	-
Available N, mg/kg	<50	50-100	100-200	>200	-
Available P, mg/kg	<5	5-15	15-80	>80	-
Available K, mg/kg	<50	50-100	100-200	>200	-
Available Ca, mg/kg	<200	200-1,000	1,000-2,000	2,000-3,000	>3,000
Available Mg, mg/kg	<80	80-150	150-300	300-500	>500
Available Fe, mg/kg	<5	5-10	10-20	20-50	>50
Available Mn, mg/kg	<2	2-5	5-20	20-50	>50
Available Zn, mg/kg	<0.5	0.5-1.0	1.0-5.0	5.0-10.0	>10.0
Available Mo, mg/kg	-	<0.05	0.05-0.20	0.20-0.30	>0.3
Available B, mg/kg	-	<0.5	0.5-1.0	>1.0	-

Abbreviations and notes for this article: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Ca = calcium; Mg = magnesium; Zn = zinc; B = boron; Fe = iron; Mn = manganese; Mo = molybdenum; Si = silicon; Na = sodium; Al = aluminum; OM = organic matter; v% = base saturation percentage; SD = standard deviation.

Table 2. Soil OM and macronutrients within selected citrus orchards, southern China.

Item	Low yielding		Mid yielding		High yielding	
	Average	SD[1]	Average	SD	Average	SD
pH	5.4	1.3	5.9	1.3	5.9	1.2
OM, g/kg	16.1	7.0	16.0	4.8	18.2	7.6
Total N, g/kg	1.1	0.3	1.1	0.2	1.6	0.3
Total P, g/kg	0.5	0.2	0.6	0.3	0.6	0.3
Total K, g/kg	14.2	4.6	15.0	5.6	15.0	4.5
Available N, mg/kg	88.3	33.3	84.4	4.8	90.0	26.9
Available P, mg/kg	15.8	19.1	22.0	27.7	22.4	22.4
Available K, mg/kg	95.6	61.2	146.6	98.1	156.2	100.4
Non-exchangeable K, mg/kg	231.3	152.4	333.7	133.3	344.0	236.2

[1]SD = standard deviation

orchards would be below the critical value for total N, 67% for total P, 59% for total K, and 56% for non-exchangeable K. Soil Ca, Mg, and Si also decreased from high to low yielding orchards (data not shown). No citrus soil fertility standards currently exist for available S and Si, but results from this study suggest 35 mg S/kg and 80 mg Si/kg as critical values. The survey found 49% of orchards had soil Ca contents lower than the critical value, 64% for Mg, 79% for Si, and 36% for S.

The established standards indicate all orchards had adequate available Zn and Mo, but were low in B. High yielding orchards had less available Na, Al, and Fe compared to low yielding orchards. Boron and Zn availability were considered as the most-limiting micronutrients, while Al represents the most important toxicity risk for the orchards investigated. Available Mn was high in all orchard groups and showed no significant difference between high and low yielding orchards. Results show 26% of orchards had soil Mn contents lower than the critical value, 57% for Zn, 86% for B, 16% for Mo, while 21% of orchards had soil Fe contents higher than the critical value, 35% for Na, and 56% for Al. Once again, standards for available Na and Al are not available for citrus, but results from this study suggest that 45 mg Na/kg and 130 mg Al/kg could be considered as suitable critical values.

Soil base saturation was also highest in high yielding orchards. This investigation suggests a standard critical value of 90% for citrus soils in China. Soil analysis indicates that 42% of soils had low soil base saturation.

The proportion of clay-sized particles was much more variable among orchards compared with other particle size fractions (data not provided). Soil clay content was highest in high yielding orchard sites. A positive relationship was also noted between clay-sized particles and improved citrus quality. Some low yielding orchards had soil layers less than 30 cm in depth and had a high proportion of gravel and sand, leading to very low nutrient supply rates.

Low soil fertility is one of the main factors limiting yield and quality for brand-name citrus orchards in south China. Over 60% of the orchard soils had low to extremely low available N, P, Mg, Si, and B. Over 50% of soils had low to extremely low OM, pH, available K, and Zn. Over one-third of soils (35 to 56%) had Al, Na, and S contents above suggested critical values. Higher citrus yield was always associated with higher soil base saturation percentage and a higher proportion of clay-sized particles. Soil OM showed a strong positive relationship with total N, available N, and available Mg. Existing farm practice varied significantly among sites and was one of the most important factors affecting soil available nutrient status. BC

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Acknowledgment

This project was supported by IPNI and the Ministry of Agriculture of China. The Soil and Fertilizer Institute(s) of Hunan, Hubei, Sichuan, Jiangxi, Zhejiang, Guangdong, Guangxi, and Fujian offered support on soil sampling, analysis, and investigation. The authors thank all supporters of this research.

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Production of navel oranges and other citrus from orchards in southern China could benefit greatly from improved soil fertility.

Nickel – from Toxic to Essential Nutrient

By E. Malavolta and M.F. Moraes

Nickel was long considered as either a non-essential or toxic element. However, more is being learned about the role of Ni as a nutrient and its activity in plants. It has shown benefits in pecan production.

"Mouse-ear" is the expression used to describe peculiar symptoms shown by leaves of pecan (*Carya illinoinensis*) and a few other plants. The tip of affected young leaves has dark spots and is rounded, resembling the ear of a mouse. The disorder, known since 1918, has affected orchards in the Southeastern U.S. Gulf Coast and Coastal Plain (Wood et al., 2004a).

The disorder initially was attributed to various causes, such as spring cold injury, viral disease, or either Mn or Cu deficiency. Leaf analysis of affected and healthy leaves revealed that the symptoms were due to Ni deficiency, caused in turn by low levels in the soil or induced by excess Zn (Wood et al., 2004b). Foliar spray of nickel sulfate ($NiSO_4 \cdot 6H_2O$) in the fall is transported into dormant tissues of shoots and buds, in a proportion sufficient for normal growth. The next spring, leaves from treated plants appear normal in shape with 7 mg Ni/kg, whereas those with symptoms showed 0.5 mg/kg. Soils of orchards exhibiting severe Ni deficiency had from 0.4 to 1.4 kg/ha of Ni (Wood et al., 2006a).

While Ni used to be considered non-essential or toxic to plants, work on pecan and other crops reveal that Ni fulfills the indirect criteria of essentiality proposed by Arnon and Stout (1939). It meets also the direct criterion: urease is an ubiquitous metalloenzyme containing Ni (Dixon et al., 1975). Eskew et al. (1983, 1984) and Brown et al. (1987) placed Ni in the list of micronutrients. As early as 1946, Roach and Barclay - in field trials carried out in England with wheat, potato, and broad beans - obtained increases in yield thanks to the application of sufficient Ni sprays.

Urease splits urea hydrolytically into ammonia (NH_3) and carbon dioxide (CO_2). Urea [$CO(NH_2)_2$] originates from the amide arginine due to the activity of the enzyme urease. Nickel deficiency, preventing the action of urease, leads to the accumulation of urea, which causes necrotic spots on the leaves. As further consequences of the deficiency, metabolism of ureides, amino acids, and organic acids is disrupted. Oxalic and lactic acid accumulate (Bai et al., 2006). These effects suggest that Ni may play a multitude of roles in higher plants. The necrotic spots associated with the deficiency correspond to local accumulation of either urea or oxalic and lactic acids, the latter indicating changes in carbon (C) metabolism, particularly impaired respiration.

Nickel is involved also in symbiotic N fixation, since it increases the hydrogenase activity in isolated nodule bacteroids (Klucas et al., 1983). Nickel ions present in the culture solution of beans and apple inhibited ethylene production (Smith and Woodburn, 1984). Field experiments described as early as 1973 showed that the addition of up to 40 g Ni/ha increased nodulation and grain yield (Bertrand, 1973). In extensive reviews, Mishra and Kar (1974) and Gerendas et al. (1999) mention that sprays with Ni salts are very affective against rust infection in cereals due to its toxicity to the pathogen and also due to changes caused in the host physiology that lead to resistance.


Photo: USDA-ARS, Dr. Bruce Wood

This pecan tree was deficient in Ni. The right branch was treated in early spring with a single foliar spray of nickel sulfate, whereas the left branch was not treated. Growth effects were visible by about 14 days after the treatment.

Plants grown in uncontaminated soils have a Ni concentration in the wide range of 0.05 to 5 mg/kg dry weight. The amplitude of the variation is due to availability in the soil and the species analyzed. Different organs or parts of the same plant may have different contents. According to Gerendas et al. (1999), the content in leaf blade is high during vegetative growth. At harvest, however, grains contain more Ni than the straw. At spring flowering, the partitioning of micronutrient in the branches of citrus disclosed a surprisingly high content of Ni, half of the total in the flowers (**Figure 1**). It is known that increasing the level of NH_3 in the leaves could cause an increase in flower induction (Lovatt et al., 1988). This might suggest that high levels of Ni in the flowers, not previously reported, could increase urease activity and generate NH_3 which would increase flowering and percentage of fruit set (Malavolta et al., 2006).

Abbreviations and notes for this article: Ni = nickel; Mn = manganese; Cu = copper; Zn = zinc; Fe = iron; Mo = molybdenum; Co = cobalt; P = phosphorus; Mg = magnesium; Ca = calcium; N = nitrogen.

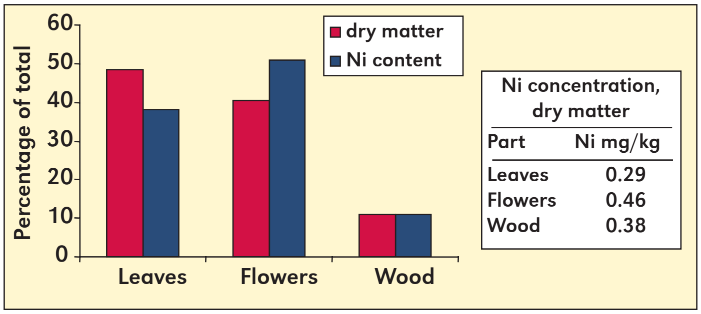

Figure 1. Nickel content of citrus in various plant parts in spring (Malavolta et al., 2006).

Symptoms of toxicity develop when excessive levels of Ni are taken up. Symptoms include chlorosis due to reduced absorption of Fe, stunted growth of the root and shoot, deformation of various plant parts, and unusual spotting of the leaves (Mishra and Kar, 1974). Plants do vary in their sensitivity or tolerance to excess Ni. For instance, beans are more sensitive than rice (Piccini and Malavolta, 1992). Toxic levels in plants are commonly of the order of 25 to 50 mg/kg.

Nevertheless, there are species which withstand exceedingly high levels of Ni in the substrate and in their tissue – the hyperaccumulators. These plants prosper in Ni-rich, usually serpentine or contaminated soils. *Alyssum bertolonii*, found in Italy and the country of Georgia (in the former USSR), contains 4,000 mg/kg in its leaves and 2,500 in seeds. In plants collected in Ni-rich soils of central Brazil, Brooks et al. (1990) found several species of hyperaccumulators: *Vellozia* spp with more than 3,000 mg/kg in its leaves and *Sebertia acuminate* with 1.17%.

Field Use and Response

Would field grown crops respond to Ni addition? Nickel requirements are of the same order as those of Mo and Co, around 0.05 mg/kg. Molybdenum deficiency has been described and response to its use is well known. Cobalt is routinely applied as seed treatment in the case of legumes. Responses to Ni, besides that shown by pecan, could show up in the future.

Nickel occurs in soils in several forms: soil solution, exchangeable and non exchangeable, in minerals, and associated with organic matter. A study of 863 soils from the U.S. gave an average concentration of 20 mg/kg and a range of less than 5 to 700 mg/kg (Uren, 1992). Analyses of 38 samples of Brazilian soils from the State of São Paulo showed soluble (DTPA) Ni in the range of less than 0.5 to 1.4 mg/kg, values considered as low. Total content was from lower than 10 to a maximum of 127 mg/kg (Rovers et al., 1983).

Nickel deficiency could be due either to low levels of available forms in the soil, or could be induced by several factors, particularly the following (Wells, 2005; Wood et al., 2006a): 1) High contents of Ca, Mg, Cu, or Zn inhibit Ni uptake. 2) Availability decreases with excessive application of lime, when pH is raised above 6.5. 3) High rates of phosphatic fertilizers or high levels of soil P reduce the availability either in the soil or within the plant itself. 4) Nematodes damage the root system and lead to severe deficiency.

One or two applications of Ni to foliage, at a concentration of 10 to 100 mg/L (plus urea and surfactant) can correct the deficiency and ensure normal growth, the treatments being made during the early canopy expansion phase, or soon after bud break (Wood et al., 2006-a). This practice, effective for mouse-ear of pecan, could serve as a trial example in other perennial fruit crops, to be checked, of course, through experimental work. Recently, Wood et al. (2006b) were able to correct Ni deficiency in pecan with sprays of an aqueous extract of *Alyssum murale*, a hyperaccumulator.

Several products are available for foliar application, including $NiSO_4 \cdot 6H_2O$ and synthetic chelates. Both the American Association of Plant Food Control Officials and the USDA have placed Ni on the list of essential nutrients. Sale and use of Ni fertilizers in the U.S. are now authorized. A new product, a chelate of ligno sulfonate with 6% Ni and 10% N, is on the market. In Brazil, the law which controls the commerce of fertilizers and amendments lists products for leaf and soil application and establishes the minimum concentration which can be registered. BC

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Spatially Variable Soil Fertility in Intensive Cropping Areas of North Vietnam and Its Implications for Fertilizer Needs

By C. Witt, B.T. Yen, V.M. Quyet, T.M. Thu, J.M. Pasuquin, R.J. Buresh, and A. Dobermann

A soil survey on more than 100,000 ha of degraded soil with intensive rice and maize cultivation in North Vietnam revealed potential multiple nutrient stresses at large scale and offered improvements of site-specific nutrient management strategies for delivery.

Nearly 60% of the rice area in Asia is irrigated, where rice is often grown in monoculture with two or even three crops per year or in rotation with maize, wheat, or other crops. Farm sizes are small, ranging from 0.3 ha in North Vietnam to 4 ha or more in the Central Plain of Thailand (Moya et al., 2004). Field sizes are even smaller since farmers often have more than one parcel.

Conditions are similar in the favorable rainfed areas where cereal production dominates, but crop diversification is emerging. Thus, there is large field-to-field variability in terms of crops, cropping practices, fertilizer use, and soil fertility status, particularly in the topsoil layer. And there is the more permanent variability in soil properties in relation to the parent material affecting soil nutrient supplies and other factors of relevance for crop production. Consequently, significant spatial variability in crop nutrient needs can be expected, here defined as a crop's demand for the external supply of inorganic fertilizer nutrients to achieve high and sustainable yield. With this paper, we hope to contribute to the discussion on how to deal with the spatial variability of crop nutrients needs in the calculation of site-specific fertilizer recommendations using a case study with small-scale rice farming in North Vietnam as an example.

Soil Survey and Descriptive Statistics

The main objective of the soil survey in the presented case study was to assess the spatial variability of soil properties that are expected to affect the i) general soil fertility for rice and maize production, and ii) the soil indigenous supply of specific nutrients in an area with suspected multiple nutrient stress. The gray degraded soils in the lowlands of the Red River Delta (RRD) in Vietnam were chosen as a study site because they represent one of the most intensely cultivated agricultural areas in the world (**Figure 1**).

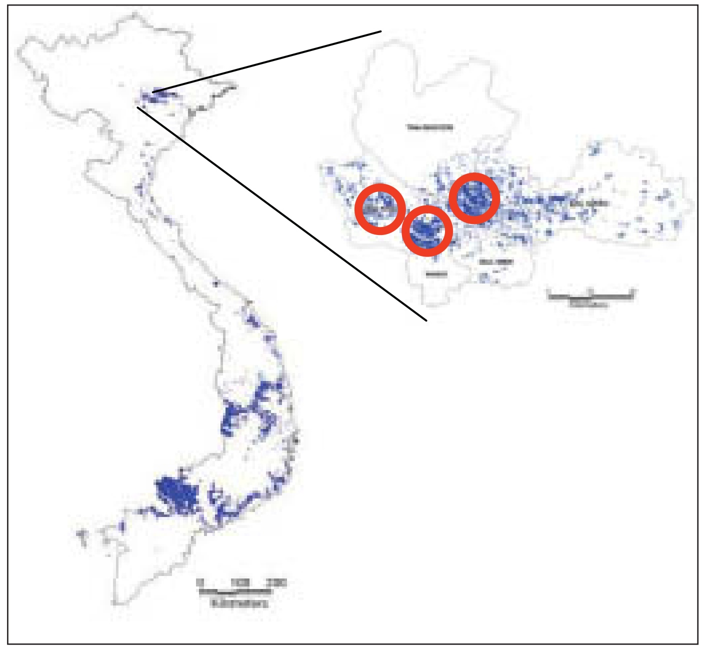

Figure 1. Location of degraded soils (blue) and study sites (red circles) near Hanoi in the Red River Delta of Vietnam.

Farmer applying fertilizer dissolved in water to a maize crop in North Vietnam.

Degraded soils of light or gray color cover about 3 million ha in Vietnam with 132,000 ha in the RRD. In the Vietnamese soil classification, degraded soils are generally characterized as low in soil fertility because of their parent material and nutrient losses caused by leaching and intensive cropping. Still, grain production in a typical rice-rice-maize rotation can reach 18 t/ha annually in the lowlands of the RRD because of excellent crop care, water availability, and significant inputs of up to 10 t/ha organic manure combined with adequate use of inorganic fertilizer. Rice and maize are planted and harvested by hand. Farm sizes range from 0.1 to 0.6 ha, but farmers own several fields of typically 200 to 1,000 m^2 in different locations. Large field-to-field variability in management practices is expected and thus, a large part of the total soil variability is likely to occur over short distances of about 20 to 100 m, which was taken into account when designing the sampling strategy.

Abbreviations and notes for this article: M ha = million hectares; Fe = iron; N = nitrogen; P = phosphorus; K = potassium; Ca = calcium; Mg = magnesium; C = carbon; CEC = cation exchange capacity.

The study area covered about 103,000 ha of degraded soil in the provinces of Vinh Phuc, Bac Giang, and Hanoi, which is about 78% of the total area with degraded soils in the RRD. Existing information included soil maps of different scale and area coverage from the years 1962 to 1979 and information on selected soil profiles (Bo et al., 2002). Soils derived from old to ancient alluvium, in parts including ferralitic material. Earlier on-farm research at selected sites in Vinh Phuc indicated low soil pH and multiple nutrient stresses, including N, P, K, Mg and possibly Ca deficiencies (Son et al., 2004).

A multi-scale sampling strategy and geostatistical interpolation techniques were used to produce detailed thematic maps of soil properties in the study area. A base set of soil samples was collected in a 1 km x 1 km grid (100 ha) following the square grid cells of a 1:25,000 topographic map. To resolve short-distance variability and model semi-variograms for quantifying the spatial variation structures in each area, additional soil samples were taken along ten transects in each province. Each transect had five sampling locations in a geometric distance progression of 0 (transect origin), 100, 200, 400, and 800 m. Transects were laid out within major soil types of each study area and went in different directions depending on the actual landscape features.

Three soil cores (0 to 30 cm or 0 to 40 cm, diameter about 3 cm) were collected from each of five individual fields that were within a radius of 50 m around the sampling location, resulting in a total of 15 soil cores per location. This approach resulted in a size of spatial support of about 1 ha (100 m x 100 m) per sampling location. The combining of samples from several fields would reduce the potentially large field to field variability at each site. This resulted in better shaped variograms needed for kriging, and it minimized problems that may result from sampling error (wrong depth) or extreme values that might be found in a single field. Soil cores were split into two equal depths and combined into one composite sample per depth. Only results from the upper 0 to 15 or 20 cm soil layer are presented here for soil samples collected at 1,014 locations. Soil parameters were analyzed at the Analytical Service Laboratory (ASL) of the International Rice Research Institute (IRRI).

Table 1 presents the descriptive statistics of elevation and the 10 analyzed soil parameters across the three study sites. The investigated degraded soils had moderate levels of organic matter (median organic C of 10.2 g/kg), which is likely related to the typically high input of farmyard manure. In 75% of all soil samples, soil pH (1:1 KCl) was 5.2 or less. Liming is generally recommended particularly for maize at a soil pH <5.3. Soils are generally low to very low in clay (median 10%), CEC (median 4.1 $cmol_c$/kg), and exchangeable K and Mg (median 0.08 and 0.3 $cmol_c$/kg, respectively). Exchangeable Ca was above the critical 1.0 $cmol_c$/kg in almost all soil samples (median 3.2 $cmol_c$/kg). The (Ca+Mg):K ratio was moderate (median 44), but low Mg levels and the wide Ca:Mg ratio (median 10.4) indicate a likely Mg deficiency considering that the Ca:Mg ratio should be about 4:1 for high rice yields. Bray-2 P levels were moderate to high ranging from 28 to 155 g/kg soil (10th and 90th percentile, respectively) with uncertain yield responses to fertilizer P application. We conclude from the descriptive statistics of this survey that yield responses to fertilizer K and Mg application are very likely in the entire study area. There is no evidence suggesting a need for variable fertilizer K and Mg rates in the sampled area. In contrast, recommendations for liming and fertilizer P application will have to consider the spatial variability of soil properties as pH and Bray-2 P assume a wider range of values including a significant portion of soil samples with pH below critical levels.

Integration of Spatial Variability in Estimating Nutrient Needs

Correlation analysis indicated only weak relationships between soil parameters that are easily estimated in the field like elevation or soil texture and soil parameters potentially related to the soil nutrient status like organic matter or exchangeable bases. It was therefore decided to map relevant soil parameters individually. The spatial distribution of pH is depicted in **Figure 2**. Soil pH was generally lower in the higher elevated

Table 1. Descriptive statistics of elevation and soil parameters in the 0 to 15 or 0 to 20 cm soil layer across all three study sites with degraded soil, North Vietnam (n=1014).

			Percentiles								
		Minimum	10%	25%	Median	75%	90%	Maximum	Mean	SD	Critical values
Elevation	m	0.7	7.4	9.4	12.0	14.8	18.6	50.8	13.1	6.1	
pH (KCl)		3.4	4.1	4.4	4.8	5.2	5.6	7.5	4.8	0.6	5.3 (maize)
OC	g/kg	1.4	6.4	8.0	10.2	12.4	14.7	36.2	10.4	3.6	
Bray-2 P	mg/kg	1.1	28	43	67	102	154.7	648	86	76	12-20
Exch. Ca	$cmol_c$/kg	0.06	1.68	2.30	3.23	4.17	5.25	18.5	3.44	1.81	1.00
Exch. K	$cmol_c$/kg	0.01	0.04	0.06	0.08	0.12	0.17	0.64	0.10	0.07	0.15-0.45
Exch. Mg	$cmol_c$/kg	0.03	0.13	0.20	0.31	0.46	0.72	3.00	0.38	0.31	1.0-3.0
CEC	$cmol_c$/kg	1.01	2.57	3.23	4.11	5.24	6.81	15.40	4.49	1.87	
Clay	%	3	5	8	10	15	23	49	13	7	
Silt	%	5	33	45	53	61	68	83	52	13	
Sand	%	-	18	24	34	44	57	82	35	15	

OC = organic carbon; CEC = cation exchange capacity. Critical values indicating likely yield responses of rice to P, Ca, K, or Mg application were based on Dobermann and Fairhurst (2000). A pH of less than 5.3 is generally considered critical for maize.

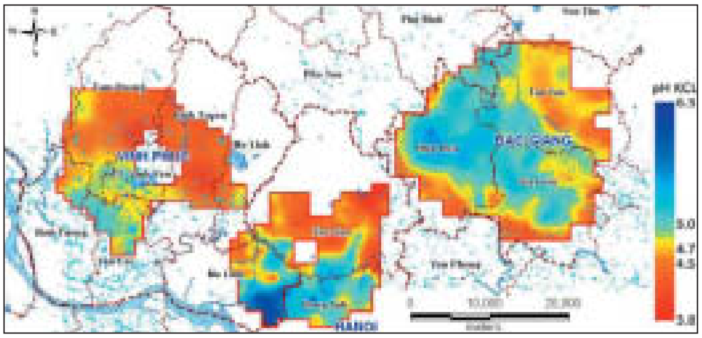

Figure 2. Soil pH (KCl) in degraded soil of North Vietnam. Interpolation by kriging.

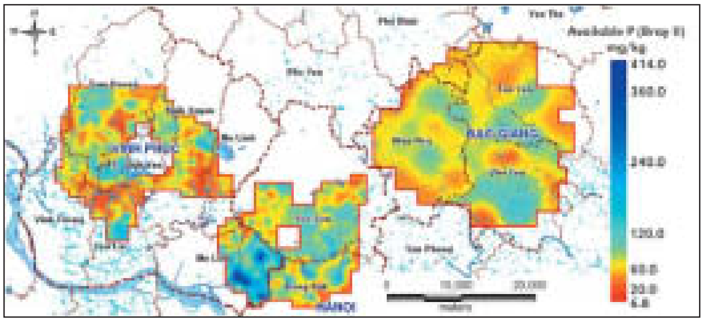

Figure 3. Available soil P (Bray-2, mg/kg soil) in degraded soils of North Vietnam. Interpolation by kriging.

areas of Vinh Phuc and Hanoi, but not in Bac Giang. There was no such correlation with other measured properties for Bray-2 P (**Figure 3**). However, there were larger continuous areas with low (red), medium (yellow), and high (blue) soil Bray-2 P levels. Interestingly, levels of both soil pH and Bray-2 P were high in the most southern part close to the city of Hanoi and near the river where crop diversification is greatest and vegetable production is common (the middle study area). Levels of Bray-2 P in this study were generally high suggesting only isolated "hot spots" with expected P deficiencies. However, studies on degraded soils in Vinh Phuc have shown rice yield responses of 0.5 to 1.5 t/ha to fertilizer P application despite high levels of Olsen-P (Son et al., 2004).

In a next step, site-specific recommendations for liming and fertilizer P application must be developed based on two or three distinct classes for pH and soil P status, respectively. In order to facilitate decision-making by farmers, there is merit in evaluating in the representative areas of the respective domains whether quantitative assessments of soil P status (such as Bray-2 P levels and yield response to P) can be associated with simple to use field-level guidelines such as historical use of fertilizer P.

Farmer with village children in North Vietnam.

Based on the presented spatial analysis of soil properties, improvements of existing site-specific nutrient management (SSNM) recommendations for farmer participatory evaluation on degraded soils in North Vietnam would thus include: i) possible adjustments of basal fertilizer N management strategies depending on organic matter, use of manure, and/or soil texture, ii) fertilizer P rates with site-specific adjustments based on a few Bray-2 P classes or historical use of fertilizer P, iii) fertilizer K rates with blanket adjustment for generally low levels of exchangeable K and with flexibility in topdressing K such as at panicle initiation in rice, iv) blanket fertilizer Mg application with use of Mg addition plots to assess whether the benefits of Mg application are associated with the farmers' use of organic inputs or other management practices, v) site-specific lime application (none, medium, high) in particular to maize based on a few pH classes (Witt et al., 2007). While N, P, and K management strategies could be combined into one SSNM practice for evaluation by farmers, the effect of Mg and lime application on yield should be evaluated in two separate addition plots embedded in the standard SSNM practice. Findings should be carefully extrapolated to degraded soils outside the study area.

Planning the survey of degraded soils in Vinh Phuc are Dr. Dobermann (left), Mr. Buy Tan Yen, and Dr. Tran Thuc Son.

Conclusions

More systematic research on the spatial variability in crop nutrient needs in small-scale rice, maize, and wheat farming in Asia is probably needed to improve the SSNM recommendations currently under development. The reliance on existing soil maps in the delineation of borderlines for fertilizer recommendations can be problematic, because maps are often old and soil classifications were not developed for agronomic purposes (Oberthür et al., 1996). New surveys and soil analysis are costly and probably only justified where multiple nutrient-stresses of unknown magnitude and spatial variability are expected, where large areas are affected, and where large scale variability in crop nutrient needs is likely to be controlled by more stable soil properties. Spatial analysis assists in the identification of most relevant soil parameters which would be useful for the development of improved survey strategies for comparable areas in a region. Soil surveys are probably not an economic tool to address short-distance variability in soil properties in Asia's rice-based systems because field-to-field variation in soil nutrient status can change quickly depending on management practices and because crop nutrient needs are not only governed by soil properties. Adequate survey strategies and classification approaches used in precision agriculture will have to be further explored to provide robust evidence that an expected variation in crop nutrient needs is manageable at an appropriate scale. Results could further contribute to the development of simplified soil classification systems for agronomic purposes (White et al., 1997; Sanchez et al., 2003) that can be provided to farmers in the form of a few simple guidelines for their use in the local adaptation and evaluation of SSNM. BC

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Acknowledgments

Funding for this research was provided by IPNI, IPI, the International Fertilizer Industry Association (IFA), and the International Rice Research Institute (IRRI).

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Conversion Factors for U.S. System and Metric Units

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

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

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

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

Other Useful Conversion Factors

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

Corn (maize) grain — bu/A x 0.062 = t/ha
Wheat or Soybeans — bu/A x 0.0674 = t/ha

FERTILIZER IS NOT A DIRTY WORD

High crop yields often come under scrutiny because of the need for fertilizers and the perception of their potential environmental impacts. Newspaper articles, letters, and advertisements from well-intended, but poorly informed, citizens seem to perpetuate old myths and clichés about modern fertilization practices. The fact is, maintaining food production for the growing world population requires the use of new technology and the intensification of management to grow more food on the existing crop land…and fertilizer is essential for accomplishing this.

Sometimes I get tired of hearing about the negative fertilizer issues that are associated with our abundant, affordable, and nutritious food supply…a truly amazing supply of healthy food that is clearly unprecedented in the history of the world! Misapplication and misuse of agricultural fertilizers have undoubtedly occurred and their impact on the environment needs to be minimized, but to fairly judge the use of fertilizers, the risks of their use should be compared with their benefits for food production.

I have had people tell me that raising yields with commercial fertilizer is somehow immoral and dangerous for our soils…that strictly organic or specialty products will meet the demand of global food production. The time has come for all of us to dispel myths about fertilizers and nutrients, and to convey a correct message to a world which is becoming increasingly urbanized and removed from what agricultural production is all about... providing healthy food.

A survey of U.S. crop production estimated that the average corn yields would decline by 40% without N fertilizer, with even greater declines if regular additions of P and K were also halted. Few people appreciate that corn yields have continued to increase in the Corn Belt of the U.S. without a similar increase in N fertilization. In fact, N use efficiency has increased at least 35% in the past 25 years (where less N fertilizer is now required to produce a bushel of grain).

Animal manure can provide a useful nutrient supply for crops…and it should certainly be used in the most beneficial manner possible. However, many people have the mistaken idea that manure has some special property for building soils. Manures contain no more nutrients than were present in the animal feed. No nutrients or organic matter are produced during the digestion process.

Recently, I received a testimonial for a special fertilizer where a few pounds of a product with N-P_2O_5-K_2O analysis of 8-2-2 was claimed to meet all the nutritional needs for 10 acres of crops! Consider for a moment that 2 lb of such a low-analysis fertilizer will provide about 3 oz. of N, and 1 oz. of P_2O_5 and K_2O spread over the entire 10 acres. Then compare this with the removal of over 1,000 lb N, 500 lb P_2O_5, and 400 lb K_2O in corn grain…or a high-yield potato crop on this 10 acres will remove 2,000 lb N, 300 lb P_2O_5, and over 2,000 lb K_2O in the tubers. It irks me that some educated people continue to believe these wild claims and provide a market for these products.

I marvel that people will eagerly buy the latest miracle product, but fail to sample the soil and to monitor their fields for fertility levels, pH, or nematodes. Proper crop nutrition plays a vital role in maintaining the world's food supply. Use fertilizer appropriately to get the best results and don't be afraid to speak out for farming practices that are such a benefit to humanity.

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