BETTER CROPS WITH PLANT FOOD

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BETTER CROPS
WITH PLANT FOOD

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Our cover: Rapeseed (Canola) fields in blossom dominate the countryside in northern France in April.
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Are Midwest Corn Farmers Over-Applying Fertilizer N?

By C.S. Snyder

U.S. corn yield (Zea mays L.) and fertilizer N consumption data are briefly reviewed, and selected Land Grant university research-based recommended N rates for corn in the U.S. are compared with public data on actual N rates used by farmers in leading corn-producing states to determine if farmers may currently be over-applying N. Contrary to popular belief, U.S. corn farmers in leading corn-producing states do not appear to be applying N at rates in excess of profit-maximizing university recommendations.

Federal and state agencies have reported increased groundwater nitrate contamination and eutrophication of lake, stream, river and coastal water resources by agricultural nutrients that escape our fields and farms (Dubrovsky et al., 2010; EPA, 2012a). Resource areas in the U.S. like the Chesapeake Bay watershed, the Mississippi River Basin watershed and the northern Gulf of Mexico have garnered considerable political and nutrient loss mitigation attention during the last two decades. The effects of N_2O emissions derived from soil management activities (which include fertilizer N use) have also been a key issue in climate change and global warming policy discussions during the last decade (EPA, 2012b; Grassini and Casman, 2012).

In the U.S., corn is often the target of environmental impact policies, perhaps because it is the crop that accounts for the largest fraction (37 to 51%) of total fertilizer N consumed annually (**Figure 1**). Although Grassini and Cassman (2012) showed that high yield and high input-use efficiencies, together with low greenhouse gas (GHG) emissions per unit of crop output (GHG intensity), are not conflicting goals in well-managed commercial-scale production fields, there is a growing fear that increases in corn acreage and fertilizer N consumption will automatically exacerbate these environmental resource challenges.

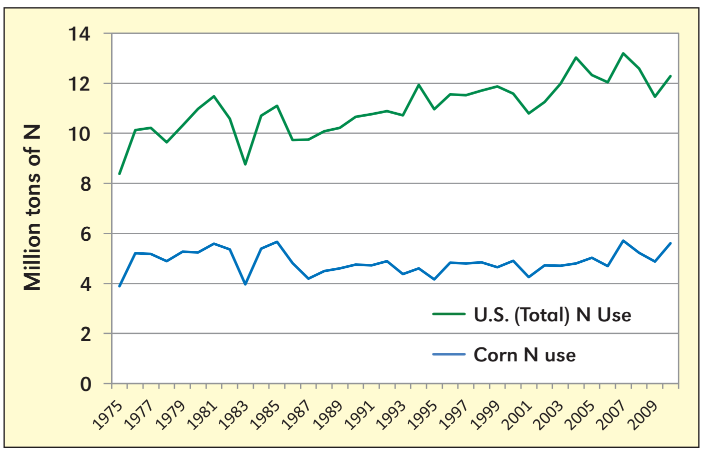

Figure 1. U.S. total fertilizer N consumption, and N used on corn. Sources: AAPFCO, TFI; http://www.ers.usda.gov/data/fertilizeruse

Modern corn production systems may take up more than 200 lbs of N/A (grain + above-ground plant residue) in achieving yields above 200 to 225 bu/A (12 to 14 t/ha). At harvest, approximately 0.7 lbs of N are removed per bushel of grain (0.0125 kg N/kg of grain). Much of the public often assumes that farmers commonly over-apply fertilizer N as they hedge their N management rates against a perceived risk of insufficient N (Millar et al., 2010). Research has shown that roughly 40 to 60% of the N applied to corn is taken up by the crop in its growing season. Much of the remaining N is stored on soil exchange sites and in soil organic matter, while a similar to smaller fraction is subject to potential environmental losses (i.e. volatilization of NH_3, NO_3^- leaching/runoff, N_2O emissions during nitrification and denitrification, and N_2 cycling back to the atmosphere during denitrification).

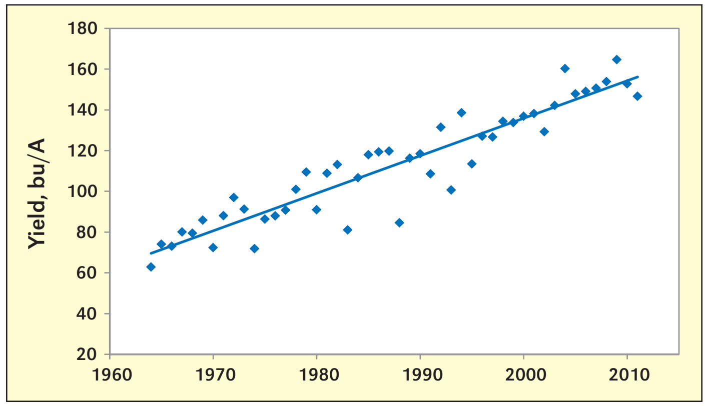

Figure 2. Yield trend of U.S. corn. Source: USDA NASS

Corn yields in the U.S. have trended steadily upward since 1975 (**Figure 2**), which has concurrently resulted in increased removal of N in the harvested grain. Fertilizer N rates applied to corn rose until the mid-1980s, declined and then rose again to approach rates used in the mid-1980s (**Figure 3**).

There has been a perception (*misperception*), which may be based in part on older reports, that N rates used by farmers on corn in the U.S. were generally higher than Land Grant University research-based recommendations (Yadav et al., 1997; Trachtenberg and Ogg, 1994).

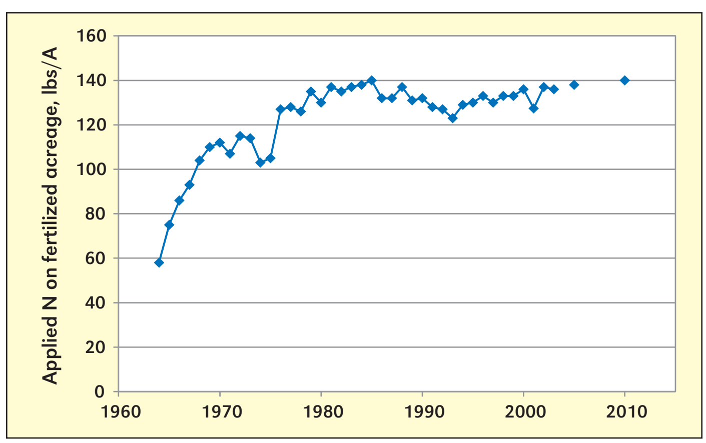

Figure 3. Fertilizer N applied to corn acres receiving fertilizer. Source: http://www.ers.usda.gov/data/fertilizeruse

Common abbreviations and notes: N = nitrogen; N_2O = nitrous oxide; NH_3 = ammonia; NO_3^- = nitrate; N_2 = nitrogen gas; $ = U.S. dollar.

To evaluate more current U.S. corn system N rate management, we used publicly available USDA survey data (Agricultural Resource Management Survey and Agrichemical Usage Data) on N rates applied to corn in 2000, 2005, and 2010 and compared them with the N rates recommended via the 'Corn Nitrogen Rate Calculator' (CNRC, 2012) to achieve profit maximization, or the maximum economic return to N (MRTN) for the same years. The MRTN data were from seven leading corn-producing states (Illinois, Indiana, Iowa, Michigan, Minnesota, Ohio, and Wisconsin) that have submitted their N rate field response data to the 'Corn Nitrogen Rate Calculator' website maintained by Iowa State University. Data for anhydrous NH_3 prices paid by farmers between March and April 2000, 2005, and 2010 ($227, $416, and $499/ton or $0.14, $0.25, and $0.30/lb of N, respectively) and average corn prices received by farmers between August to October in the same years ($1.69. $1.82, $4.02/bu, respectively), were used as input data for the 'Corn Nitrogen Rate Calculator'. The MRTN calculation for corn following soybean, excluding nonresponsive site data, was chosen, as opposed to corn following corn for the purposes of this article. Corn N fertilization needs are usually less when corn follows forage legumes or soybean than when corn follows corn (CNRC, 2012).

The results of these N rate comparisons for leading corn-producing states in the U.S. are shown in **Table 1**. Averaged within and across years, USDA survey data and agricultural statistics indicate that farmers applied N for corn in these states at rates that were frequently lower than the MRTN rates (see last three columns in Table 1) prescribed by some of the leading Land Grant Universities in 2000, 2005, and 2010.

Clearly, much of the current focus on "excess N rates" and calls for nutrient use reductions by Midwest U.S. farmers may be misplaced. Robertson and Vitousek (2009) recognized that appropriate crop N management is not all about N rate and stated, "Mismatched timing of N availability with crop need is probably the single greatest contributor to excess N loss in annual cropping systems."

Based on the results in this brief article and other published reports, more emphasis should be placed on all 4Rs of Nutrient Stewardship: right source at the right rate, right time, and right place; to achieve more sustainable crop production, improved nutrient use efficiency, and environmental resource protection. BC

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Table 1. Rates for maximum return to N as prescribed by the 'Corn Nitrogen Rate Calculator' compared with USDA survey data on N rates actually applied by farmers in 2000, 2005, and 2010 in the respective states.

	N rate prescribed by 'Corn Nitrogen Rate Calculator' for MRTN[1]			USDA-surveyed state fertilizer N rate on corn acres receiving N			Difference (surveyed state rate minus MRTN)		
State (region of state)	2000	2005	2010	2000	2005	2010	2000	2005	2010
	---------- lbs of N/A ----------								
Iowa	139	122	143	131	141	142	-8	19	-1
Illinois (north)	150	134	155						
Illionis (central)	174	155	180	161	146	167	-13	-9	-13
Illinois (south)	179	158	186						
Indiana (west and northwest)	171	158	175	153	147	178	-18	-11	3
Indiana (east and central)	207	193	210						
Indiana (remainder)	181	162	187						
Michigan	135	124	139	110	128	122	-25	4	-17
Minnesota	113	103	120	114	139	125	1	36	5
Ohio	181	161	188	162	161	141	-19	0	-47
Wisconsin (VH/HYP soils)	125	107	130	133	138	92	8	31	-38
Wisconsin (M/LYP soils)	98	94	105						
Wisconsin (irrigated sands)	209	200	209						
Wisconsin (nonirrig. sands)	130	124	130						
Ave. of white colored rows	**148**	**133**	**154**	**138**	**143**	**138**	**-11**	**10**	**-15**

[1]MRTN is maximum return to N, using the 'Corn Nitrogen Rate Calculator' found at: http://extension.agron.iastate.edu/soilfertility/nrate.aspx

Improvement of Diagnosis Accuracy of Phosphate Status for Ukrainian Soils

By Anatoly Khristenko and Svetlana Ivanova

Through an analysis of the effect of soil properties on the accuracy of the Olsen P soil test, a refined method and interpretive scale for available soil P supply was developed for use in alkaline soils.

Studies performed at the Institute for Soil Science and Agrochemistry Research named after O.N. Sokolovsky, National Academy of Agrarian Science, Ukraine, show that some chemical methods used for the determination of plant available elements involve large errors. In particular, the error for determining available soil P or K based on former Soviet Union soil testing standards can reach 100 to 200% or more. Most methods include the use of strong acid solutions that can underestimate results for all coarse (sandy and loamy sandy) soils, as well as for strongly acid ($pH_{KCl} < 4.5$) soils of different textures, and can overestimate results for soils with high contents of primary P-containing apatite minerals.

Presently eight national soil test standards and five standard drafts have been developed for Ukraine's 32 million ha of arable land. The process began with the identification of Ukrainian regions and soil types for which specific chemical methods of determining plant available N, P, and K are most advisable. The potential effects of soil composition and physical properties on the results of chemical analyses were taken into consideration. New scales of soil supply for available P or exchangeable K were developed for some methods that together specify methods for determining plant available N, P, and K for all soils of the country.

The use of State standards, including the Olsen, Machigin, Chirikov, Kirsanov, and Karpinskii–Zamyatina methods (described below), has generally meant that available P status of arable soils under extensive agricultural use fall within the low-to-medium supply levels, while available K status is generally considered medium. This agrees with well-known empirical data that demonstrates high efficiency of mineral fertilizers, especially P fertilizers, on all types of arable soils of Ukraine, including its chernozems. New regulatory soil tests explained below, demonstrate an increase in accuracy of the diagnosis of soil fertility. The subsequent correction of fertilizer application rates, and more rational distribution of fertilizers among fields and crops, can increase use efficiency by an average of 30%.

Errors in soil testing theory and methodology create overestimation (or underestimation) of results for not only individual fields, but also entire regions. An illusion of rich chernozems on loessial rocks is related to the increased content of P-bearing apatites and K-bearing feldspars in these soils. However, P or K present in these minerals are not directly available to plants. At the same time, these elements are partially extracted by strong acid solutions, including 0.02 N HCl (pH 1.0, Kirsanov method) and 0.5 N CH_3COOH (pH 2.5, Chirikov method).

Common abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; Ca = calcium; KCl = potassium chloride; K_2SO_4 = potassium sulfate; HCl = hydrochloric acid; CH_3COOH = acetic acid.

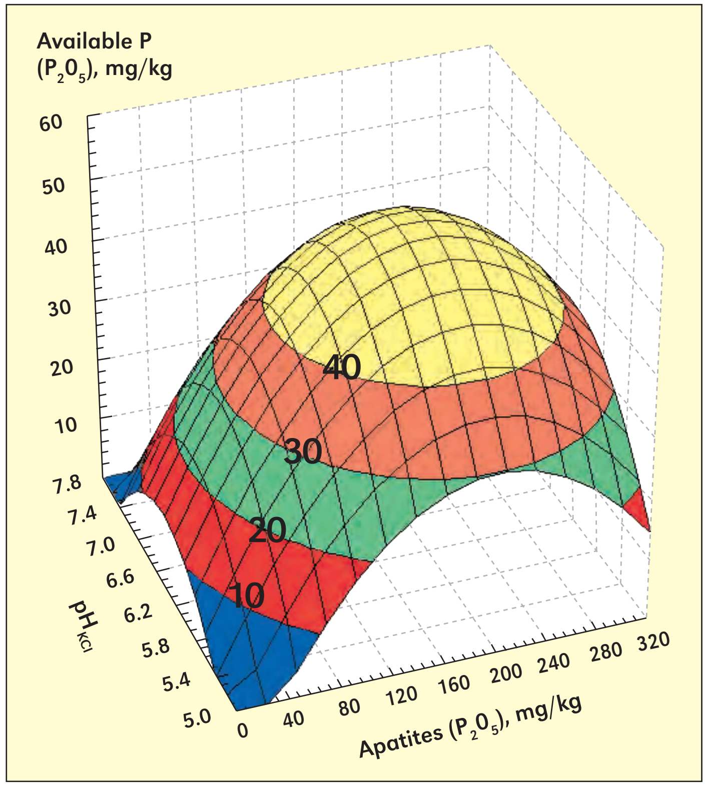

Figure 1. Determination of P in 21 soil samples representing common soil types of Ukraine and Russia by the Egner–Riehm method depending on soil pH and apatite content (Ca–P fraction).

Reported data shows that the unbiased assessment of soil fertility and available forms of macro- and micronutrient is a global challenge.

Shortcomings of the methods based on the use of acid solutions are largely typical for all methods using extractant solutions with pH below 4.5: Bray–Kurtz 2 (pH 1.0), Mehlich 1 (pH 1.2), Arrhenius (pH 2.0), Mehlich 3 (pH 2.5), Mehlich 2 (pH 2.6), Van Lierop (Kelowna, pH 2.7), Egner–Riehm (pH 3.6), Bray–Kurtz 1 (pH 3.5), Egner–Riehm–Domingo (pH 4.2), etc. For example, we found that the determination of P by the Egner–Riehm method in soils with strongly acid or alkaline reaction entails the underestimation of the results (**Figure 1**). An increase in the content of apatite in the soil, on the contrary, overestimates the results. The content of apatite is reflected in the Ca–P fraction (i.e. Chang–Jackson method).

The tendency toward a "decrease" in the content of P in soils with the very high content of apatite (prevalent in the Ukrainian steppes) is related to their alkaline reaction. The

Table 1. The content of plant available P in the main arable soils of Ukraine from the acid, alkaline, and salt methods depending on soil pH and apatite content.

Soil type*	Content of particles <0.01mm, %	pH_{KCl}	P_2O_5, mg/kg Chang–Jackson, Ca–P fraction	Chirikov, pH 2.5	Olsen, pH 8.5
Albeluvisols Umbric	9	4.5	34	34.0	19.6
Albeluvisols Umbric	18	4.9	75	35.0	19.8
Cambisols Eutric	32	3.8	45	1.9	20.7
Phaeozems Albic	48	3.8	104	2.1	20.9
Chernozems Luvic	32	5.4	118	10.0	19.8
Chernozems Calcic	56	6.8	201	79.9	19.5
Chernozems Calcic	54	6.7	244	80.0	20.0
Chernozems Chernic	48	6.0	273	132.0	25.2
Chernozems Chernic	55	6.4	297	161.0	25.6
Chernozems Calcic	60	6.9	326	170.0	24.5
Mollic Gleysols	27	6.6	806	345.1	30.3

*according to the World Reference Base for Soil Resources (WRB) nomenclature

Table 2. Assessment of P supply in Chernic Chernozem soil with chemical and biological methods used in a pot study.

Soil texture	Field experimental treatment*	P_2O_5, mg/kg Ion-exchange chromatography	Olsen	Karpinskii–Zamyatina (DSTU[†] 4729)	P_2O_5 in oat biomass, %
Clay loam	Control	20.0	19.1	0.31	0.52±0.09
	$P_{1,200}$**	58.9	52.9	1.75	0.70±0.09
Loam	Control	31.0	24.0	0.44	0.58±0.11
	$N_{400}P_{400}K_{480}$***	119.1	124.9	5.84	0.81±0.11

*Fertilizer treatment for the field from which soil was collected for use in the greenhouse pot study; subscripts indicate kg/ha on oxide basis.
**A single application of P with no cropping prior to sample collection.
***A long-term study where the indicated rates were the average application for one 5-year rotation with the experiment conducted for 11 rotations (total fertilizer applied was 11 times the rates shown).
[†]Denotes National Soil Test Standard

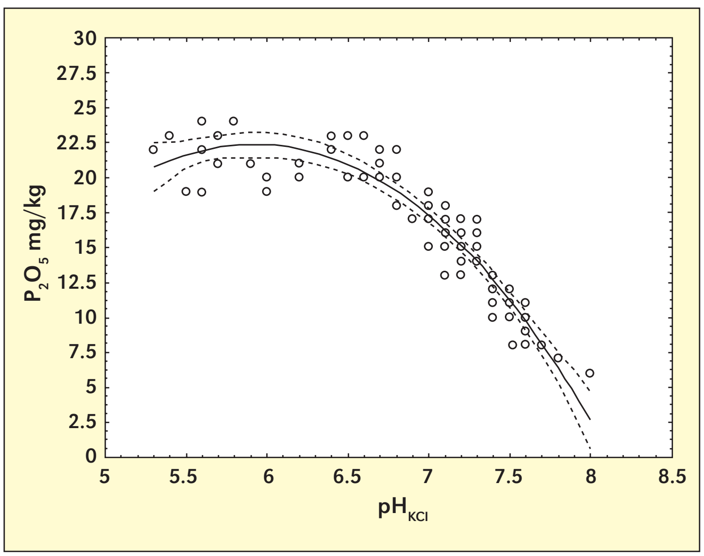

Figure 2. Results of the determination of available P by the Olsen method depending on soil pH.

authors evaluated this through a combination of methods based on different principles: chemical methods, ion-exchange chromatography, and pot studies. A statistical analysis of data from an automated information data bank (more than 1,500 soil samples) was also performed. On the basis of these studies, a conclusion was drawn about the advisability of the wide use of so-called "mild" methods (based on the use of salt and weakly alkaline extractant solutions). A 30-year-long comparative study of different methods showed the superiority of the method based on the use of a sodium bicarbonate solution (Olsen et al., 1954). It was found that the particle-size distribution and other soil properties (e.g. presence of apatite, acid reaction) had almost no effect on the Olsen method's results. The coefficient of correlation was $r < 0.33$.

The content of available P in the Ukraine's unfertilized and underfertilized soils, as determined by the acid method, can vary from very low to very high values of P supply (**Table 1**). According to the Olsen method, Ukrainian soils always are within the low-to-medium P supply range. Data obtained by the Olsen method for acid and neutral soils always agree with the soil fertility estimated using other mild methods. The adequacy of the P status estimation was also confirmed by pot study (**Table 2**).

The Olsen-P method has wide applicability across Ukrainian soils: from acid Cambisols Gleyic and Albeluvisols Umbric to Chernozems Calcic and Kastanozems Haplic. In comparison, the scope of the Chirikov method is significantly smaller–only recommended for podzolized soils (Albeluvisols Umbric, Phaeozems Albic, Chernozem Luvic). Although the Olsen method is primarily designed for the analysis of alkaline soils, its use for these soils could result in the underestimation of P supply. The higher the soil alkalinity, the lower the result (**Figure 2**). As a result, the general opinion is that alkaline soils are poorly supplied with available P. The parallel use of salt solutions (Karpinskii–Zamyatina, 0.03 N K_2SO_4 with pH 5.8; Schofield) shows that no actual decrease in available P occurs in alkaline soils. Thus, the disappearance of P is an illusion related to a limitation of the method as an alkaline extract loses its extraction capacity under alkaline conditions. The maximum underestimation is about 18 mg P_2O_5/kg—a value equivalent to the effect of a single application of at least 600 kg P_2O_5/ha in a heavy soil.

Rigorous application of soil test protocols lose their value given a lack of official nutrient sufficiency ranges in terms of plant available P supply. The P status of soil cannot be impartially assessed without adequate nutrient sufficiency ranges. Available literature data are contradictory (**Table 3**). Studies performed at the Institute for Soil Science and Agrochemistry Research reveal that the P sufficiency ranges estimated by the Olsen method in accordance with the P sufficiency ranges developed earlier (Yanishevskii, 1996; Agrochemical methods of soil examination, 1975) do not usually agree with the values obtained by other alkaline and salt methods.

Table 3. Soil supply with plant available phosphorus as determined by the Olsen method.

	Soil test P_2O_5, mg/kg		
Phosphorus sufficiency ranges	Yanishevskii, 1996	Agrochemical methods of Soil Examination, 1975	Proposed ranges
Low	< 11	< 25	< 18
Medium	11-23	25-50	19-34
Increased	23-41	50-90	35-50
High	> 41	> 90	51-66
Very high	-	-	> 67

The authors propose refined P sufficiency ranges, as determined by the Olsen method, which now coincide with estimates of soil P supply from other mild chemical methods (Machigin, pH 9.0; Chang–Jackson, Al–P fraction, pH 8.5; Karpinskii–Zamyatina, pH 5.8). A category of very high supply was also added in hopes of further contributing to the more rational use of the resources available. Optimum plant available P for stable, high crop yields lies within the range corresponding to high P supply. An increase above the optimum level results in an abrupt decrease in crop response to P fertilizer. Liberal application of P fertilizers to highly alkaline soils is also unadvisable as high alkalinity (pH_{KCl} 8.0 or pH_{water} 8.5 and higher) is frequently due not only to the presence of calcium carbonates, but also to the presence of Na. The latter compound is detrimental to the growth and development of many agricultural crops, which abruptly decreases the efficiency of fertilizers applied.

Mathematical models and the corresponding software were developed by the authors for the determination of the actual supply of alkaline soils with available P depending on the pH_{KCl} or pH_{water} values (Khristenko, 2009). The use of these mathematical models or software, as well as the improved scale for soil P supply, will contribute to the optimization of fertilizing systems and, hence, expenditures per ha of fertilized area. For example, finding that the supply of soil P is 25 mg P_2O_5/kg (medium P supply) rather than 5 mg P_2O_5/kg (low P supply), the farmer can significantly reduce fertilizer application without fear of crop yield reductions.

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IPNI Scholar Award Application Deadline is June 30

The International Plant Nutrition Institute (IPNI) is proud to continue its support of the IPNI Scholar Award program in 2012 and would like to remind all prospective candidates that the June 30 deadline for submitting applications is quickly approaching. This Award of USD 2,000 (two thousand dollars) is an annual competition amongst students enrolled in graduate degree programs supporting the science of plant nutrition and crop nutrient management. Funding for the Scholar Award program is provided through the support of IPNI member companies, primary producers of nitrogen, phosphate, potash, and other fertilizers.

The IPNI Scholar Award recipients are selected by regional committees of IPNI scientific staff. The selection committee adheres to rigorous guidelines while considering each applicant's academic achievements. The awards are presented directly to the students at their universities and no specific duties are required of them. Graduate students in the disciplines of soil and plant sciences including agronomy, horticulture, ecology, soil fertility, soil chemistry, crop physiology, and other areas related to plant nutrition are encouraged to apply. Graduate students must also attend a degree-granting institution located in any country with an IPNI Program.

This student award program continues to highlight the most promising and emerging young scientists working in plant nutrition research worldwide. In 2011, IPNI has named 20 (twenty) graduate students as recipients of the IPNI Scholar Award. A listing of the global distribution of the IPNI Scholars can be found at our awards website >www.ipni.net/awards<. More information is available from IPNI staff, or from participating universities.

Evaluation of In-season Nitrogen Management for Summer Maize in the North China Plain

By Shicheng Zhao and Ping He

Field experiments tested N fertilizer at different rates and ratios of basal:topdress application. A total N rate of 120 to 180 kg/ha was shown to maximize grain yield and, with split application, reduce N inputs by 25 to 50% compared to typical farm practice within the North China Plain.

The North China Plain (NCP) is one of the most important areas for summer maize production in China. The crop grows from the middle of June to the end of September and high yields in this intensively farmed region have been obtained over the past 2 decades through excessive N fertilization (He et al., 2009; Ju et al., 2009). This results in the accumulation of soil N as leachable NO_3^-, which risks groundwater pollution and low NUE by crops (Cui et al., 2009; Zhao et al., 2010). At present, typical farmer practice is to apply all their N fertilizer at once, either as a basal application before planting or as topdressing during the 7-leaf stage. Neither of these patterns of N application can provide a soil N supply that is in synchrony with crop N demand.

It is essential to develop appropriate N management methods that can overcome any environmental problems or low NUE that results from excessive N application. It is also important to promote the development of sustainable agricultural production within this region. The most logical approach to increasing NUE is to combine applications of basal N and topdressed N at critical growth stages that coincide with crop N demand and seasonal soil N supply. High-yielding maize varieties show increased N uptake after anthesis, and the 8 to 10-leaf stages are critical times for topdressed N (Barbieri et al., 2008). Since current N management practices for summer maize in this region are not tailored to these growth requirements, this study evaluated in-season N management based on grain yield and crop N uptake, and provides a theoretical base for reducing N application and enhancing NUE in the NCP.

Field experiments were conducted simultaneously on farms near the cities of Hengshui and Xinji (37°N, 115°E), in Hebei province, from July to October 2009. The two sites were approximately 25 km apart, and had similar climatic conditions. The previous crop at both sites was winter wheat. In Hengshui, the soil texture was clay loam, and the chemical properties in the 0 to 20 cm soil profile were: pH 8.4; organic matter 13.4 g/kg; Olsen-P 8.9 mg/kg; and NH_4OAc-K 103 mg/kg. Before planting, the NH_4^+-N content in the 0 to 20, 20 to 40, 40 to 60, 60 to 80, and 80 to 100 cm soil layers were 3.1, 0.9, 2.5, 13.2, and 10.0 mg/kg, respectively, and NO_3-N content were 12.2, 11.6, 12.7, 7.2, and 6.3 mg/kg, respectively. In Xinji, the soil texture was sandy loam, and the chemical properties in the 0 to 20 cm soil profile were: pH 8.6; organic matter 0.82 g/kg; Olsen-P 6.2 mg/kg; and NH_4OAc-K 97 mg/kg. Before planting, the NH_4^+-N content in the 0 to 20, 20 to 40, 40 to 60, 60 to 80, and 80 to 100 cm soil layers was 1.2, 1.2, 1.1, 1.0, and 0.8 mg/kg, respectively, while the NO_3-N contents were 14.8, 11.9, 10.4, 7.8, and 6.1 mg/kg, respectively.

Besides a zero-N control, seven N treatments varied the amount and/or ratio of basal: top-dressed N (**Table 1**). A 0:240 treatment (i.e. 0 kg basal and 240 kg topdressed) was designed to simulate the N application pattern commonly used by farmers. Basal N (urea) was broadcast before planting followed by 600 m^3/ha of irrigation water; while topdressed N was applied at the V10 (10-leaf) stage. Before planting, all plots received 90 kg P_2O_5/ha and 90 kg K_2O/ha. All winter wheat residues were left on the field. The maize variety was Zhengdan 958.

Table 1. Experimental design for nitrogen applied to summer maize (Hengshui and Xinji, Hebei).

Treatment	Basal	Topdress	Topdress date
	---------- kg/ha	----------	
N0	0	0	-
N120 (0:120)[a]	0	120	June 25
N120 (30:90)	30	90	June 25
N120 (60:60)	60	60	June 25
N180 (0:180)	0	180	June 25
N180 (45:135)	45	135	June 25
N180 (90:90)	90	90	June 25
N240 (0:240)[b]	0	240	July 17

[a] Values in the parenthesis indicate basal:topdress N rate.
[b] Farmers' practice treatment.

Grain Yield, Crop N Uptake and Utilization

In Hengshui, no significant difference in grain yield was found among N supplying treatments, and only the low rate of 120 kg N/ha was required to achieve the maximum grain yield (**Table 2**). Combining basal N with topdressed N promoted crop N uptake, RE_N, and AE_N; but did not impact HI or HI_N with the exception of the 0: 240 treatment, which generated a significantly lower HI than some treatments that received basal N.

The Xinji site was more responsive to N as all treatments receiving basal N out-yielded the control, and the 180 kg N/ha rate achieved the maximum grain yield (**Table 2**). When N was applied solely as a topdressing, no significant differences in grain yield were found among the N0, N120 (0:120), and N180 (0:180) treatments. Crop N uptake, RE_N, and AE_N showed similar trends to those observed in Hengshui. Treatments

Common abbreviations and notes: N = nitrogen; P = phosphorus; NUE = nitrogen use efficiency; NH_4OAc-K = ammonium acetate-extractable K; NH_4^+ = ammonium; NO_3^- = nitrate; RE = recovery efficiency; AE = agronomic efficiency; HI = harvest index.

that received basal N showed higher HI values than the zero-N control, but there were no significant differences in HI_N except for the low HI_N value of the N240 (0:240) treatment.

At both sites, RE_N and AE_N increased along with basal N rate. Maize grown in Hengshui showed higher grain yield, crop N uptake, and NUE than in maize grown in Xinji; however, the HI and HI_N values were lower for maize grown in Hengshui (**Table 2**).

Nitrogen Balance

The initial N_{min}, apparent N mineralization, and crop N uptake in Hengshui were higher than those values obtained in Xinji (**Table 3**). Thus, indigenous N supply in Hengshui was higher than that in Xinji. Compared with treatments that only received top-dressed N at V10 stage, those that received both basal and top-dressed N showed reduced residual N_{min} after maturity. In Hengshui, soil residual N_{min} was higher in the N240 (0:240) treatment than in the N120 (0:120) treatment. In Xinji, however, no significant difference was found among the three N treatments that did not receive basal N. At both sites, the apparent N losses during the maize growing season increased with total N application rate. For treatments receiving the same amount of total N, the apparent N loss increased with topdress N rate, and these values were significantly higher in Xinji than in Hengshui.

Discussion and Conclusions

In this study, basal application of N did not affect grain yield when N was also being topdressed in Hengshui because of high indigenous N supply. In Xinji, the highest grain yield was achieved via application of N as basal and top-dressed fertilizer. This despite reports that indicate no basal N fertilizer is recommended to improve NUE when soil N indigenous supply is considered adequate (Zhao et al., 2012).

In Hengshui and Xinji, the total N rate of 120 and 180 kg N/ha—half applied basally and half topdressed—could meet the N demands of high yielding maize during the entire growing season. The optimal N application rates determined here for maximum grain yield indicate that N fertilizer could be reduced by more than 50% and 25% in one summer maize season in Hengshui and Xinji, respectively. Therefore the

Table 2. Maize grain yield, crop N uptake, nitrogen use efficiency (RE_N and AE_N), HI, and HI_N of different N treatments (Hengshui and Xinji, Hebei).

Sites	Treatment	Grain yield, kg/ha	Crop N uptake, kg N/ha	RE_N, %	AE_N, kg/kg	HI, %	HI_N, %
Hengshui	N0	7,384b[a]	179c	-	-	54.5a	60.2a
	N120 (0:120)	7,877ab	207b	23.6d	4.1b	54.2a	59.9a
	N120 (30:90)	8,181a	231ab	43.2b	6.6a	54.8a	60.7a
	N120 (60:60)	8,231a	247a	56.6a	7.1a	54.5a	60.6a
	N180 (0:180)	8,037ab	212b	18.6d	3.6bc	53.3ab	60.5a
	N180 (45:135)	8,088ab	217b	21.5d	3.9b	54.7a	62.9a
	N180 (90:90)	8,181a	239a	33.5c	4.4b	52.3ab	60.6a
	N240 (0:240)	8,074ab	240a	25.3d	2.9c	50.1b	57.1a
Xinji	N0	6,158c	103d	-	-	57.6a	70.1a
	N120 (0:120)	6,299c	124c	17.5e	1.2d	51.7b	63.9ab
	N120 (30:90)	6,908b	153a	41.9a	6.2ab	55.8a	67.3ab
	N120 (60:60)	6,769b	147ab	36.3b	5.1b	55.8a	65.2ab
	N180 (0:180)	6,677bc	137b	19.0e	2.9c	51.3b	64.0b
	N180 (45:135)	7,228ab	151ab	26.2c	5.9b	56.2a	68.8ab
	N180 (90:90)	7,435a	154a	28.3c	7.2a	56.6a	67.4ab
	N240 (0:240)	6,912b	155a	21.8d	3.1c	50.2b	62.4b

[a] Within each column, mean values followed by different letters are significantly different ($p < 0.05$).

Table 3. Nitrogen balance sheet for treatments applied during maize growing season (Hengshui and Xinji, Hebei).

		N output			N input		
Site	Treatment	N rate (1)	Initial Nmin[a] (2)	Apparent N mineralization (3)	Crop N uptake (4)	Residual Nmin[b (5)] (5)	Apparent N loss (1)+(2)+(3)-(4)-(5)
Hengshui	N0	0	217	108	179c[d]	146d	0
	N120 (0:120)	120	217	108	207b	242b	-4d
	N120 (30:90)	120	217	108	231ab	237b	-22e
	N120 (60:60)	120	217	108	247a	218c	-20e
	N180 (0:180)	180	217	108	212b	257ab	36b
	N180 (45:135)	180	217	108	217b	256ab	32b
	N180 (90:90)	180	217	108	239ab	247b	19c
	N240 (0:240)	240	217	108	240ab	272a	54a
Xinji	N0	0	157	61	103c	114d	0
	N120 (0:120)	120	157	61	124b	155ab	51c
	N120 (30:90)	120	157	61	153a	131c	46c
	N120 (60:60)	120	157	61	147ab	138c	45c
	N180 (0:180)	180	157	61	137b	156ab	97b
	N180 (45:135)	180	157	61	151ab	149bc	96b
	N180 (90:90)	180	157	61	154a	143bc	93b
	N240 (0:240)	240	157	61	155a	165a	130a

[a] Initial N_{min}, soil mineral N in 0 to 100 cm soil layer before planting.
[b] Residual N_{min}, soil mineral N in 0 to 100 cm soil layer after harvest.
[c] Within each column, means followed by different letters are significantly different ($p < 0.05$).

apparent risk to N loss can be reduced if compared with traditional N fertilization practice. The question of whether N rates of 120 and 180 kg/ha can sustain high grain yields in the next crop season requires further study. However, for optimum N management, fertilizer applications should be tailored to each specific field or region, because N availability and N use vary according to crop growth, soil fertility, and soil texture. BC

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4R Nutrient Stewardship – Update

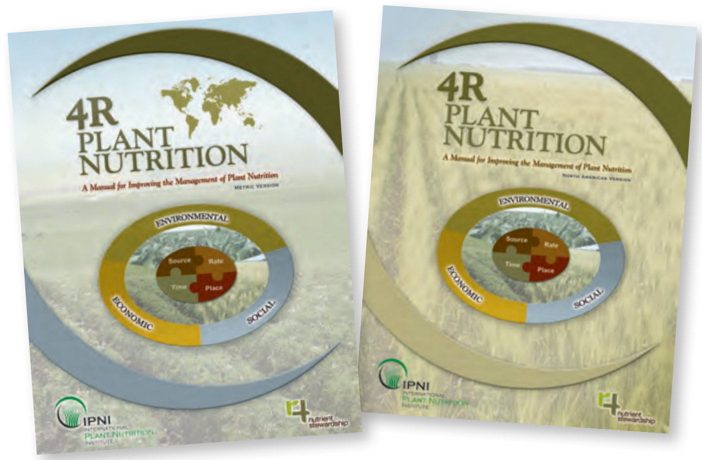
Metric Version of 4R Plant Nutrition Manual Now Available

In further support 4R Nutrient Stewardship and its approach to implementing fertilizer best management practices, the International Plant Nutrition Institute (IPNI) has released a second version of its 4R Plant Nutrition Manual—one that is fully metric.

This metric version is a follow-up to IPNI's initial release of the 4R Plant Nutrition Manual in March 2012, which was designed to fit a North American user through its predominant use of U.S. (Imperial) units.

4R Nutrient Stewardship is one of IPNI's core strategies to support agriculture's ability to meet the world's production needs in a sustainable manner. The 4R concept is simple—apply the right source of nutrient, at the right rate, at the right time, and in the right place—but the implementation is knowledge-intensive and site-specific. 4R Nutrient Stewardship also considers economic, social, and environmental dimensions of nutrient management and because of these considerations 4R Nutrient Stewardship has been recognized by the world's fertilizer industry as an essential approach to the ensuring sustainability of agricultural systems.

The 4R Plant Nutrition Manual includes chapters on the scientific principles behind each of the four R's or "rights". It discusses adoption of 4R practices on the farm, approaches to nutrient management planning, and measurement of sustainability performance. The manual is intended to help the reader adapt and integrate the fundamental 4R principles into a comprehensive method of nutrient management that meets the criteria of sustainability. A mix of learning modules and case studies demonstrate the universality of the 4R Nutrient Stewardship concept through its application to diverse cropping systems used within small enterprises, large commercial farms, and plantations.



Both versions of the 4R Plant Nutrition Manual are in the form of a 130 page wire-bound book (8½ x 11 in.).

For details on ordering please visit our store at www.ipni.net/store or contact IPNI at circulation@ipni.net or 770-825-8082. Discounts are available for quantity orders of the manual. For more details or resources on 4R Nutrient Stewardship please see our 4R Portal at www.ipni.net/4R. BC

Use of Boundary Lines in Field Diagnosis and Research for Mexican Farmers

By Armando Tasistro

Better diagnostic tools that avoid the bias of the diagnostician and are more quantitative in nature are badly needed, especially in developing countries. The application of boundary lines to the databases that are routinely collected by advisers could serve as a useful alternative. Furthermore, they can provide valuable research information in a shorter time and more representative conditions than traditional experiments.

The diagnosis of field problems involves not only their identification, but also their prioritization. These are critical steps that need careful attention. Boundary lines can be used to prioritize field problems. After Webb (1972) wrote about the biological significance of boundary lines, they have been used by numerous researchers in a wide range of applications. Boundary lines have potential advantages (Shatar and McBratney, 2004) such as: the facilitation of site-specific applications because each sampled point in a field can be considered separately; the possibility of identifying a single yield-limiting variable at each location; and there is no need for a separate process of variable selection. However, they also have a number of shortcomings (Lark, 1997; Shatar and McBratney, 2004) that include: fitting boundary-line curves can be difficult; they do not provide evidence about the nature of the joint action of the factor under consideration with others; and, the potential dependence of the location of the boundary line on relatively few data points limits its robustness.

As an example of their application, the four hypothetical scattergrams in **Figure 1** show the relationship between maize yield and four variables: plants/ha, soil organic matter, soil Na, and soil EC. The database used could have typically been collected by agricultural advisers through their regular visits to farmers. As an example of the application of this approach as a diagnostic tool, we will assume that we have sampled a maize field and found the values for each of the four variables shown by the vertical lines in each graph. Each value of the four variables is associated with an expected maize yield given by the corresponding boundary line. If we arrange the expected yields in increasing order, we get the sequence soil Na < soil EC < soil organic matter < plant/ha, which suggests that in this example soil Na is the one that most limits maize yield.

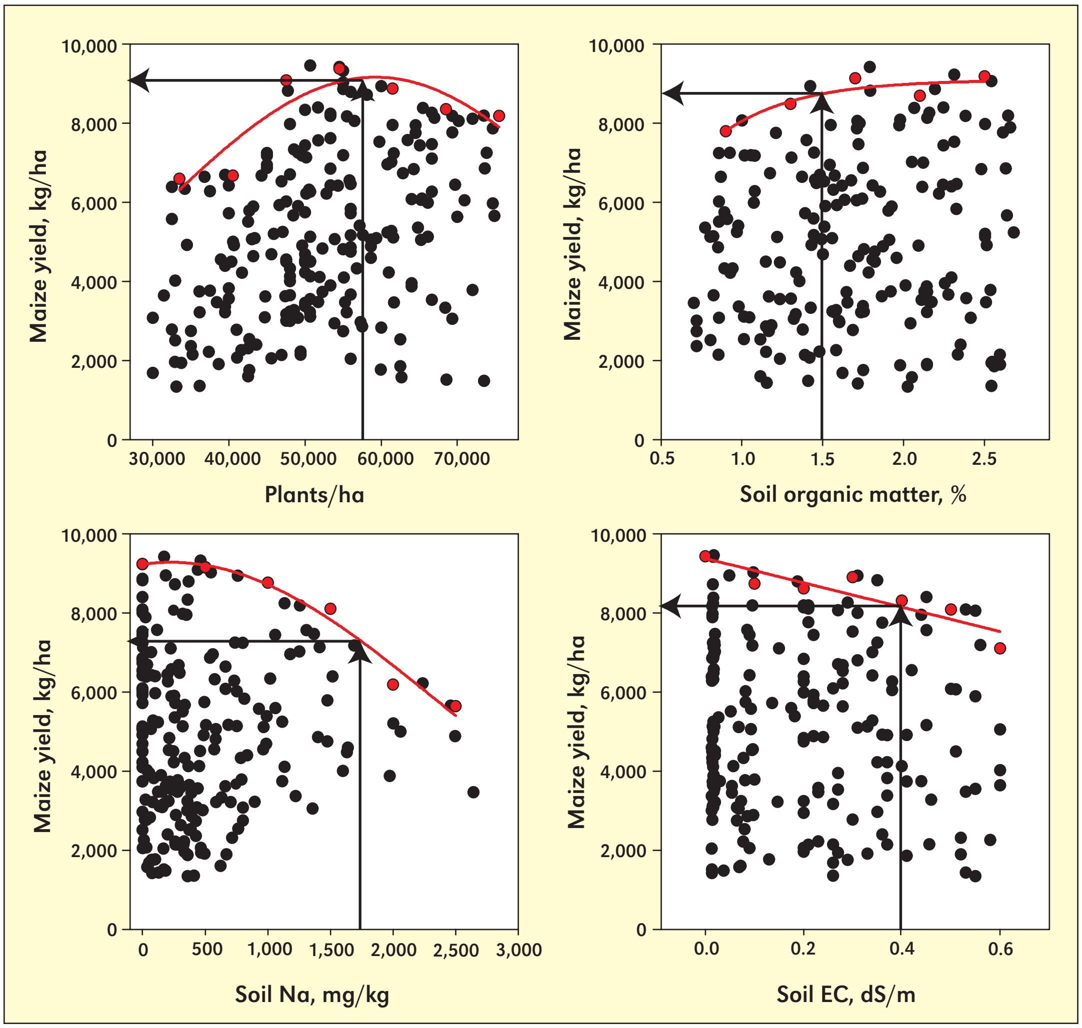


Figure 1. Scattergrams showing the hypothetical relationships between maize yield and maize plants/ha, soil organic matter content, soil Na content, and soil salinity (EC).

Examples from Mexico

Boundary lines were fitted to maize data sets made from observations taken in 1,850 farms and the results of the analysis of 38 soil samples from "La Fraylesca" region in Chiapas collected at harvest time. This sampling was carried out by private consultants as part of a training program on field diagnosis. The maize fields were sampled following the guidelines by Lafitte

Common abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; Al = aluminum; Na = sodium; EC = electrical conductivity.

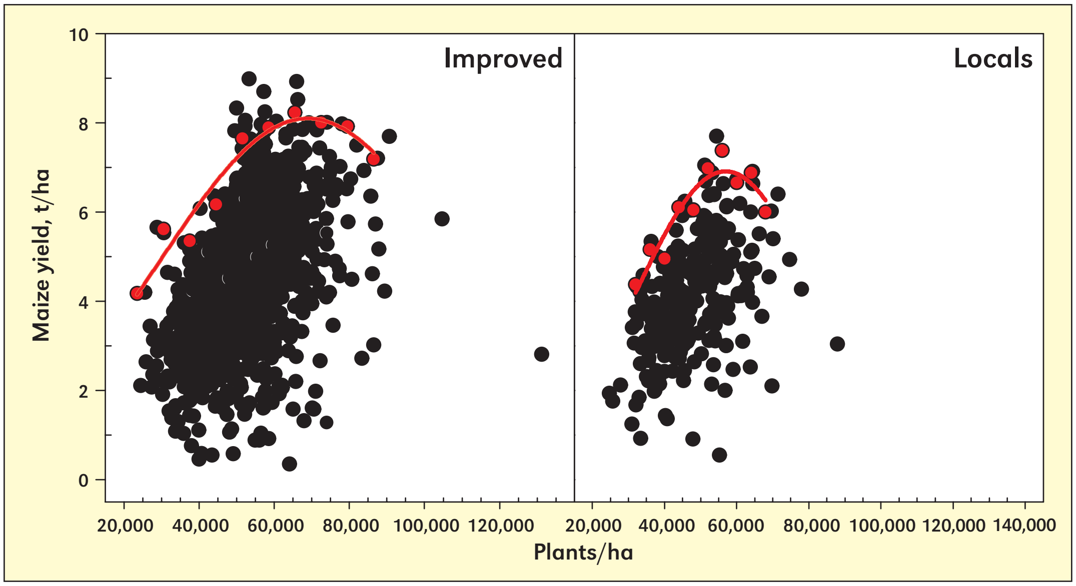


Figure 2. Maize yields of improved and local genotypes under the range in plant populations observed in Chiapas, Mexico.

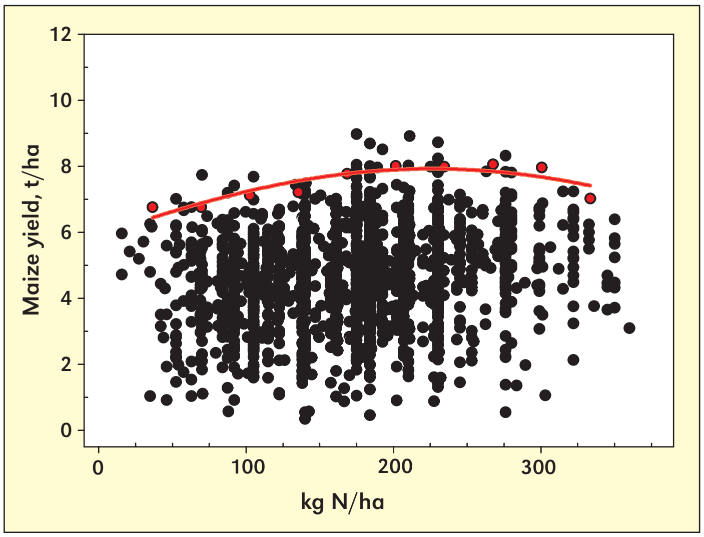


Figure 3. Maize yields of improved genotypes under the range of total N applications in Chiapas, Mexico.

(1993) where eight randomly chosen 5.0 m-long segments of crop rows were marked, and observations were carried out in the 1st, 5th, and 10th plant in each row. The results for each farm correspond to the mean of the 8 rows. Soil samples were composites of 10 to 15 sub-samples of the top 0 to 25 cm layer taken from the area of the 8 rows.

Boundary lines were adjusted following Schmidt et al. (2000) where scattergrams relating grain yield to each variable of interest were built; the data set for each scattergram was split-up in equidistant segments on the basis of the values of the x-axis variable; data points in each segment were assumed to relate to the arithmetic mean of the x-values of the respective segment; the data points in each segment were then ordered according to the dependent variable; 99% percentiles were computed and used as boundary points. A line was fitted and drawn to those boundary points.

Most of the visited farmers in Chiapas grew improved maize genotypes, which yielded more and tended to respond to higher plant densities than local genotypes (**Figure 2**). The grain yield of improved genotypes responded to the total amount of N applied showing a peak at 226 kg N/ha (**Figure 3**).

Ears with scattered grains and blank spaces in-between are indicative of possible insect damage to silks, extremely hot conditions, or drought during pollination (Lafitte, 1993). Data in **Figure 4** show that yield dropped more markedly when those symptoms were visible in more than 15% of the ears.

The partial or total absence of grain rows might be the result of several factors, including P deficiency, excessive plant population, poor plant arrangements, or that the ears showing

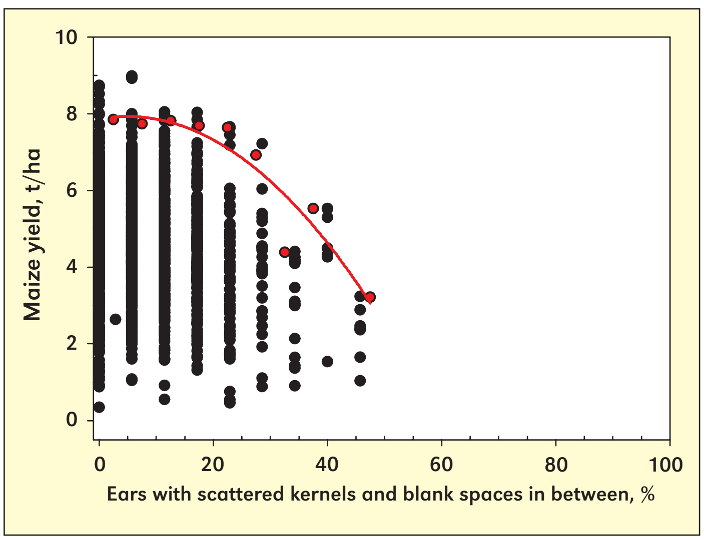


Figure 4. Effect of ears with scattered grains and blank spaces in between on maize yields in Chiapas, Mexico.

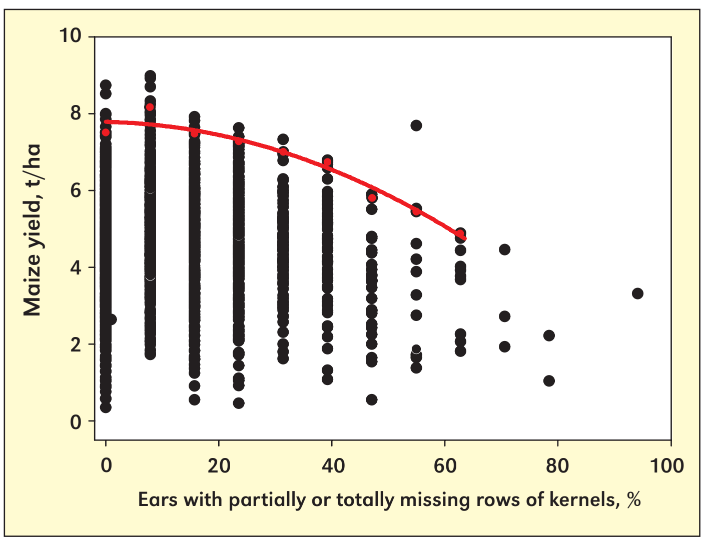


Figure 5. Effect of ears with some rows of grains partially or completely missing on maize yields in Chiapas, Mexico.

the problem are second ears in prolific plants (Lafitte, 1993). Maize yield seems to be affected less by these problems (**Figure 5**) than by those shown in **Figure 4**.

Root and stalk lodging showed low incidences, but stalk lodging seemed to affect yields more markedly than root lodging (**Figure 6**), which could be related to the more drastic effects of stalk breaking on grain filling.

Figure 7 shows the relationships between grain yield and some of the soil properties analyzed. Soil acidity is an important limitation for maize in La Fraylesca. Dominant sandy textures, humid climate, and a history of usage of ammonium sulphate as an N source, have contributed significantly to that problem. As **Figures 7a** and **7b** illustrate, maize yield is reduced 50% when exchangeable Al concentration exceeds 1.0 $cmol_c$/kg or occupies more than 20 to 30% of the cation exchange sites. Although soil K content can be severely limiting for maize yield, as indicated by the data in **Figure 7c**, the application of K is still quite limited among farmers in that region. Soil organic matter can also be a critically limiting factor (**Figure 7d**), which reinforces the need to adopt conservation agriculture practices and stop the burning or removal of crop residues.

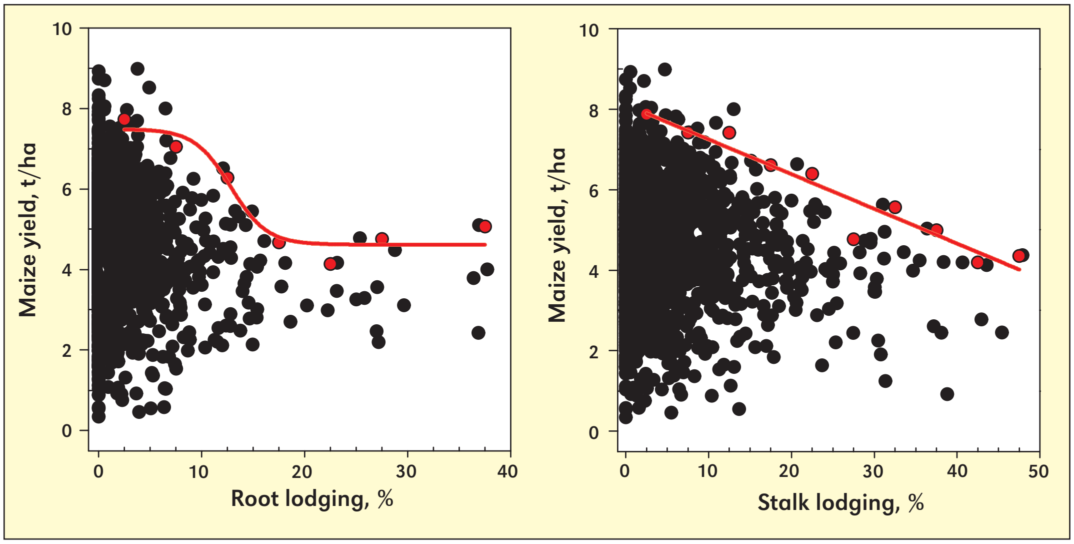


Figure 6. Effects of root and stalk lodging on maize yields in Chiapas, Mexico.

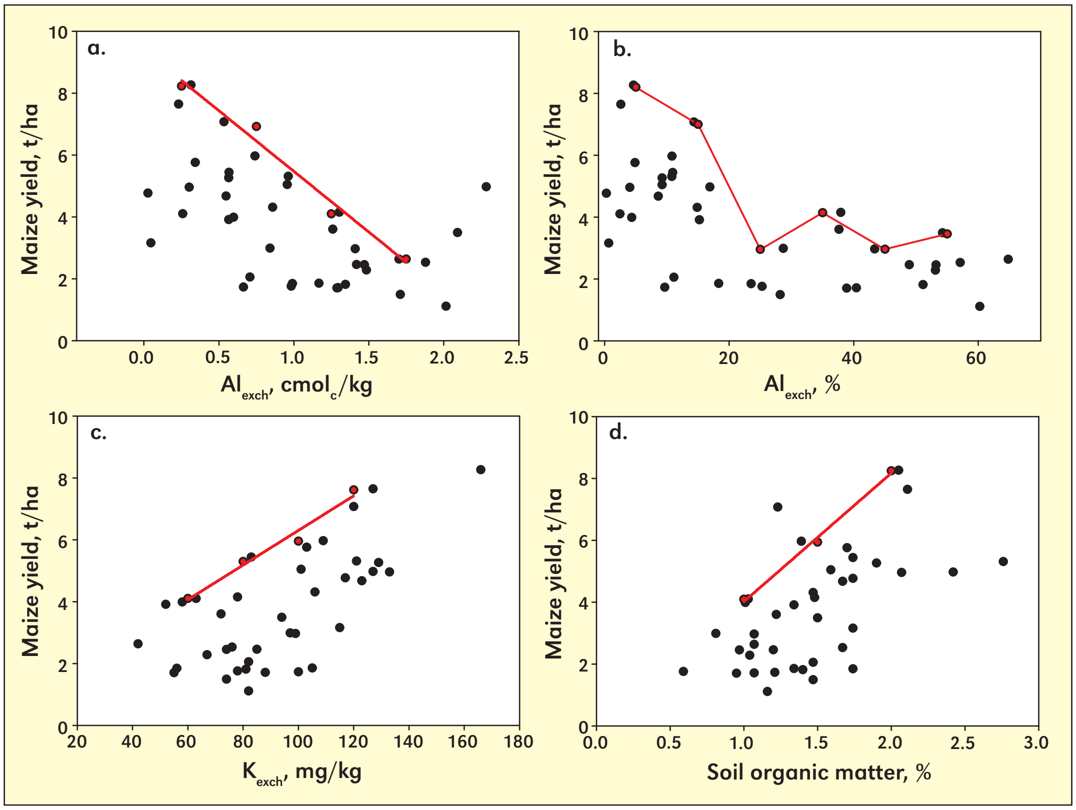


Figure 7. Effects of soil exchangeable Al (a) and (b), soil K (c) and soil organic matter (d), on maize yields, Chiapas, Mexico.

Prior to this work, the knowledge about the effects of plant population, N rates, or other management components on maize yield in the region was limited to results taken from conventional research plots. Given the limited nature of these studies in terms of geographical areas or environmental conditions, the application of their results can be limited by uncertainty about the variability between the conditions under which the results were obtained and those under which they will be applied. This brings attention to the potential of data collection and analysis through boundary lines as a research tool. As evidenced by the results of this study, properly planned surveys can efficiently provide representative data to compliment conventional research plots.

The increasing use of surveys in agriculture as well as of precision agriculture tools are providing greater opportunities to develop databases amenable to analysis through boundary lines. BC

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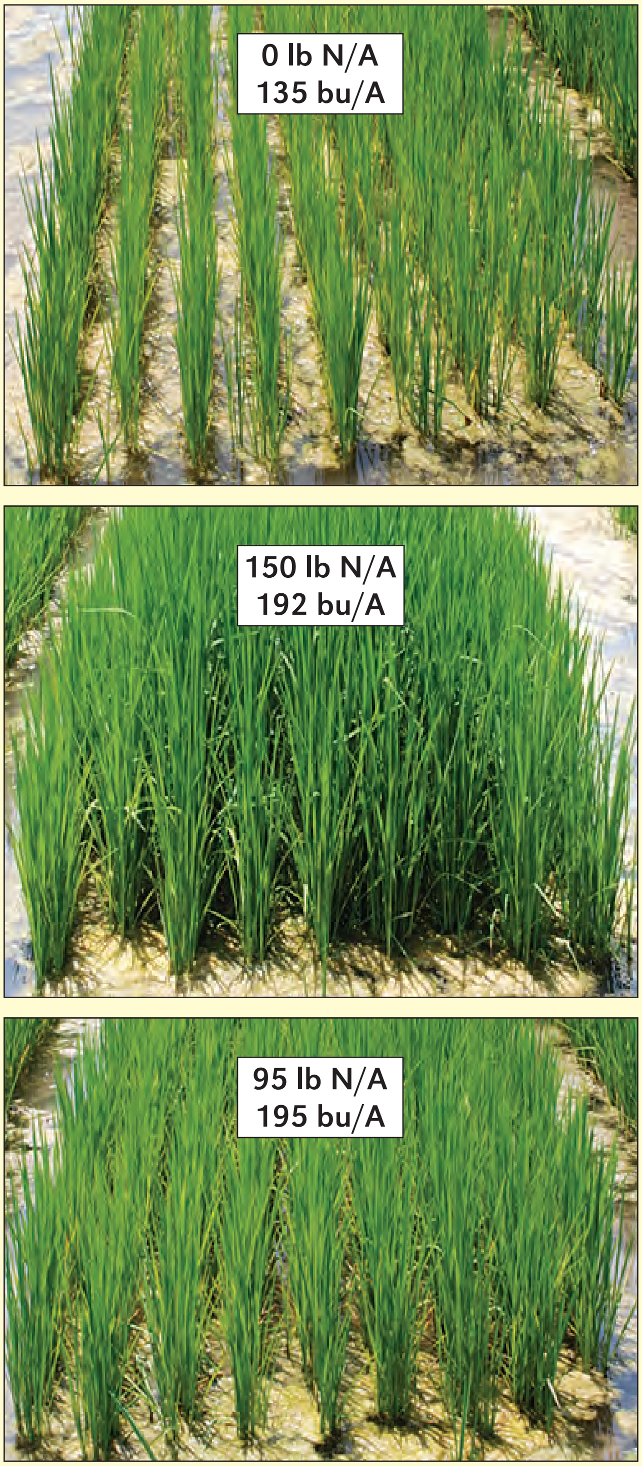
Development and Implementation of N-STaR: the Nitrogen-Soil Test for Rice

By T.L. Roberts, A.M. Fulford, R.J. Norman, N.A. Slaton, T.W. Walker, C.E. Wilson, Jr., D.L. Harrell, and G.N. McCauley

Researchers across the Midsouth U.S. rice producing states of Arkansas, Louisiana, Mississippi and Texas set out to develop a soil-based N test in 2003, which could be used to determine site-specific N fertilizer rate recommendations for rice. The test has now been implemented.



Visual comparison of N rate treatments used in the small-plot validation studies across the Midsouth. Notice the differences in color and rice biomass based on N rate treatment and the corresponding rice yields.

Current N fertilizer recommendations are based on a combination of three factors; soil texture, cultivar, and previous crop. To improve N fertilizer management for Midsouth U.S. rice producers, a stronger emphasis on the soil's ability to supply N should be considered. There have been several papers that focused on alkaline-hydrolyzable N and its use for corn N recommendations (Mulvaney et al., 2001; and Williams et al., 2007), with mixed results on a regional basis. Currently, there is not a reliable soil-based N test for domestic rice producers. Researchers have experimented with soil-based N tests as long as there has been soil fertility research and although some methods have shown promise for rice grown in a greenhouse (Wilson et al., 1994), nothing has stood out as a solid method for predicting rice response to N fertilizer in the field. Identification of a simple soil test to measure the amount of available soil N is becoming more and more important and will be essential for the long-term sustainability of domestic rice production. Benefits of a soil N test are not just about optimizing economic or agronomic returns, but making environmentally sound N fertilizer decisions.

The majority of rice in the Midsouth is produced using a direct-seeded, delayed-flood production system with similar response to N fertilizer on silt loam soils regardless of whether you are in Northern Arkansas or Southern Louisiana. Direct-seeded, delayed flood rice production boasts the highest NUE of any cereal crop when managed properly and can consistently result in values exceeding 75%. Thus, direct-seeded, delayed-flood rice production is the ideal candidate for the development and use of a soil-based N test. The successful correlation and calibration of a newly developed soil test method hinges on three factors; 1) consistent N mineralization, 2) high and consistent NUE and 3) a highly reproducible soil test method that quantifies the forms of N that feed the plant throughout the growing season. Over the past 6 years, researchers collaborated to develop N-STaR: the N-Soil Test for Rice, which will allow field-specific N fertilizer management for Midsouth rice producers.

Initial work with N-STaR centered on the development of a steam distillation technique that could fractionate potentially mineralizable soil-N and offer an alternative to the diffusion method used in the Illinois Soil N Test (ISNT) (Mulvaney et al. 2001; Bushong et al., 2008). Extensive laboratory studies using the ^{15}N tracer identified the specific soil organic N compounds that are being quantified using N-STaR and indicated that amino sugar-N, amino acid-N and NH_4-N were the primary chemical compounds (Roberts et al., 2009). The N compounds quantified using N-STaR are not prone to the loss mechanisms of leaching or denitrification. The relative

Common abbreviations and notes: N = nitrogen; NUE = nitrogen use efficiency; N-STaR = N-Soil Test for Rice; NH_4-N = ammonium-nitrogen.

stability of these soil N fractions coupled with the fact they are the most readily mineralizable-N compounds may account for the high correlation of this soil test method for rice versus a pre-sidedress nitrate test (PSNT) that is commonly used for upland crops. During this same time period, N response field trials were established across the Midsouth in an attempt to begin the process of correlation and calibration. As with any nutrient, the success of a soil test method is only as good as the soil sample taken. Early on, research indicated that a standard 6-in. soil sample was not sufficient to capture the soil N status and accurately predict crop response to N. Soil sampling protocols were adjusted to encompass the entire rooting depth of rice produced on silt loam soils, which literature had shown to be roughly 24 in. Following the increase in soil sampling depth, the accuracy of N-STaR measurements improved considerably. Statistical analysis indicated that the correct sampling depth for rice produced on silt loam soils was 0 to 18-in. and coincided with the effective rooting depth of the rice crop, which is the depth over which the plant can access and assimilate N. Years of research experience identified the need for higher N rates for rice produced on clay soils, and over time it became obvious that N-STaR soil test values were highly related to soil texture and that separate calibration curves would have to be developed for silt loam and clay soils. As silt loam soils comprise the vast majority of rice acreage in the Midsouth, silt loams were the primary focus of our research and currently have the most complete data set.

Over the course of three years, data were obtained from N response trials in Arkansas, Louisiana, Mississippi and Texas (**Figure 1**), but the correlation and calibration curves were not completed until sites were found where there was little to no response to N fertilizer. One of the most difficult aspects of the research was identifying sites that did not respond to N fertilizer and this is partly due to the fact that most silt loam soils in the Midsouth have relatively low organic matter (<2.5%) and amounts of soil residual-N. In the fall of 2008 a completed calibration curve was released for rice produced on silt loam soils (**Figure 2**). The predictive ability for N-STaR, or any soil-based N test, needed to be high due to the responsive nature of rice to N fertilizer, input costs associated with N fertilizer, and the environmental aspects of poorly managed N fertilizer.

Immediately following the completion of the N-STaR calibration curve, research began in replicated, small-plot trials to validate the ability of the soil test to predict site-specific N rates for rice produced on silt loams. Field validation studies were conducted on sites separate from the areas used to develop the correlation and calibration curves and were primarily located in producer fields to mimic real-world settings. During the first year of field validation it became obvious that site-specific N rates using N-STaR often resulted in rice with less biomass and lighter green in color (**see photos**) than rice receiving the standard recommendation of 150 lb N/A. However, results from the small-plot validation studies indicated that yields obtained using N-STaR were similar or higher than the standard practice at 17 of the 18 sites located across Arkansas, Louisiana and Mississippi. Observations made during the small-plot validation studies indicated that disease pressure from sheath blight and false smut were also generally lower in the N-STaR treatments, which provided a site-specific N rate rather than the standard practice of 150 lb N/A. These results provided evidence that N-STaR could predict the N mineralization potential of silt loam soils in the Mississippi River delta and predict the N fertilizer rates required to maximize rice yields. The final step was to evaluate the N-STaR technology in large-scale, commercial production fields.

Figure 1. Relative locations of small-plot N response trials used during the correlation and calibration of N-STaR.

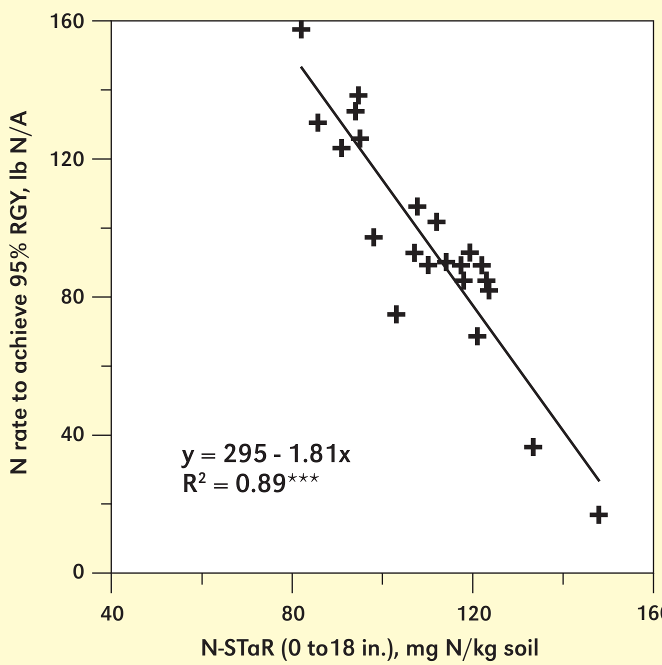


Figure 2. Calibration of N-STaR for the 0 to18 in. depth increment which predicts the N rate required to produce at least 95% relative grain yield for rice grown on silt loam soils.

Large-scale production fields offer a new dimension of field variability error that is not often seen in small-plot research. A number of fields were sampled and analyzed by N-STaR and the determination was made that the 0 to 18-in. soil sample depth required for N-STaR analysis resulted in lower levels of field variability than a traditional 0 to 4-in. soil sample used for routine soil analysis of rice nutrient requirements. During 2011, 17 field-scale strip trials were conducted across the Midsouth US comparing the N-STaR site-specific N rate to the producer practice within a large-scale production field. Treatments were replicated and harvested with a commercial combine, weighed using a weigh wagon, and moisture determined. Statistical analysis indicated that for 15 of the 17 sites, the N-STaR rate recommendation resulted in yields that were equal to or higher than the producer practice. The average N rate reduction across all sites was 55 lb N/A, and in some cases the N rate reduction was as much as 105 lb N/A with no statistical yield difference.

The release of N-STaR for silt loam soils within the Midsouth has been well received by growers. Continuing research with N-STaR will focus on the completion of a correlation and calibration curve for rice produced on clay soils. Other ongoing research is the development of the N-STaR technology for soft red winter wheat production in Arkansas, which indicates the need to sample 6-in. deep and is currently being validated in small-plot trials. The success of N-STaR in rice and wheat promises more efficient N use in Midsouth agriculture. BC

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Mohamed El Gharous Joins Staff of IPNI as Consulting Director of North Africa Program

Dr. Mohamed El Gharous

The International Plant Nutrition Institute (IPNI) is pleased to announce the addition of a new scientific staff member. Dr. Mohamed El Gharous will serve as Consulting Director of IPNI's newly established regional program in North Africa. The program will work collaboratively with the National Agronomic Research Institute (INRA) on projects and activities of mutual interest. Dr. El Gharous will be based in Settat, Morroco.

"The establishment of this program in North Africa marks another milestone for IPNI's regional representation within the African continent," said IPNI President Dr. Terry Roberts. "Mohamed's knowledge of arid and semi-arid agriculture will be a great addition to the knowledge-base of IPNI, and his representation of the North African region will be highly valued by our members and staff."

Dr. El Gharous received a Horticultural Engineer degree (B. Sc.) in 1980 from the Agronomy and Veterinary Hassan II Institute in Rabat, Morroco. He was hired by INRA in Morocco in 1980. Mohamed subsequently received his M.Sc. (Agronomy) in 1987 and his Ph D. (Soil Science) in 1994—both from Oklahoma State University in Stillwater, USA.

Dr. El Gharous's research career began by examining soil fertility for cereals in arid and semi-arid regions. He has since been responsible for coordinating the soil and plant testing laboratory at the Aridoculture Center at Settat (INRA-Settat) as well as research on soil test calibration in arid and semi-arid zones. He has coordinated the cereal and soil management research sub-programs at INRA-Settat, conducted research on soil fertility and fertilization within the aridoculture program, and assisted the management of the Aridoculture Center.

Selected research highlights include following the evolution of P and K in soils under wheat-fallow rotation and quantifying their residual effects; improving fertilizer recommendation techniques in calcareous soils of Morocco; exploring composting and compost effects on soil quality and plant nutrition; defining fertilizer formulas adapted to Moroccan soil and climatic conditions and crops; and adaptation and improvement of soil and plant analyses methods.

Presently, Dr. El Gharous is also Head of the Regional Center for Agricultural Research in Settat; and a member of the Faculty of Science and Technology at the University of Hassan I, Settat, where he lectures and serves as a supervising committee member for a number of graduate student programs. Dr. El Gharous is a nationally recognized expert on the subjects of fertilization, the research programs of INRA-Settat, and Zero-Tillage. He is a member of the Franco-Moroccan joint scientific committee for PRAD Projects (Research Projects in Agriculture for Development), President of the Sports and Cultural Association of Agricultural Research (INRA Club at Settat), and Vice President of the Cultural Association of the Chaouia Ouardigha Region. BC

HarvestPlus Zinc Fertilizer Project: HarvestZinc

By Ismail Cakmak

The first phase of the HarvestPlus Zinc Fertilizer Project has assessed the potential for crop response to Zn-containing fertilizer in a number of target countries where soils are unable to produce staple foods with adequate Zn. Foliar spray of Zn fertilizers is highly effective in increasing Zn concentrations of cereal grains. However, attention should be paid to the timing of Zn spray. Soil application of Zn-containing fertilizers is more important for improving crop yields.

Zinc deficiency is a well-documented micronutrient deficiency problem both in human populations and in crop production globally. It is estimated that about 50% of the cereal-cultivated soils globally are deficient in plant available Zn, leading to reductions in crop production and also nutritional quality of the harvested grains (Graham et al., 1992; Cakmak, 2008). Since cereal grains/seeds contain inherently very low amount of Zn, growing cereal crops on potentially Zn-deficient soils further decreases grain Zn concentrations. It is, therefore, not surprising that the widespread occurrence of Zn deficiency in human populations occurs mostly in regions where cultivated soils are low in plant available Zn and cereal-based foods are the major source of daily calorie intake (**Figure 1**). Up to 75% of the daily calorie intake of the human beings living in the rural areas of the developing world comes only from cereal-based foods with very low Zn concentrations and also low bioavailability of Zn.

Common abbreviations and notes: N = nitrogen; Fe = iron; Zn = zinc.

Zinc deficiency causes severe impairments in human health, including impairments in brain function and development, weakness in immune system to deadly infectious disease and alterations in physical development. Zinc deficiency has been shown to be responsible for deaths of about 450,000 children under 5-years old annually (Black et al., 2008). Zinc deficiency is also becoming an important public health problem in developed countries. Low dietary intake of Zn is a known health issue in USA, UK and Australia—especially among women, children and elderly people (Watt et al., 2001; Gerrior, 2002). Today, increasing Zn concentration of stable food crops, especially cereal grains, is therefore, an important challenge and a high priority research area.

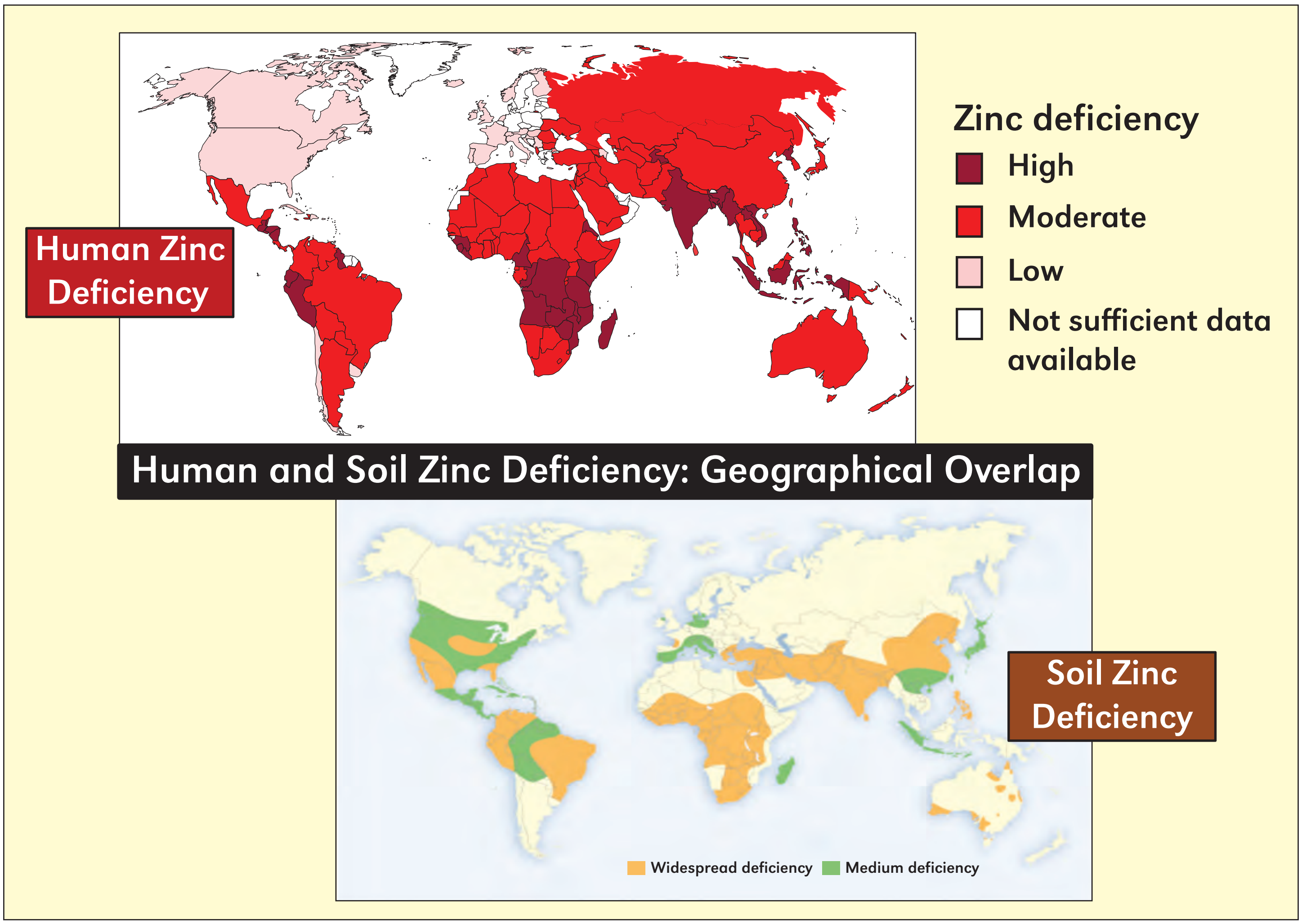

Figure 1. Geographical overlap of soil Zn deficiency and human Zn deficiency. (Sources: http://www.izinc.org; Alloway, 2008).

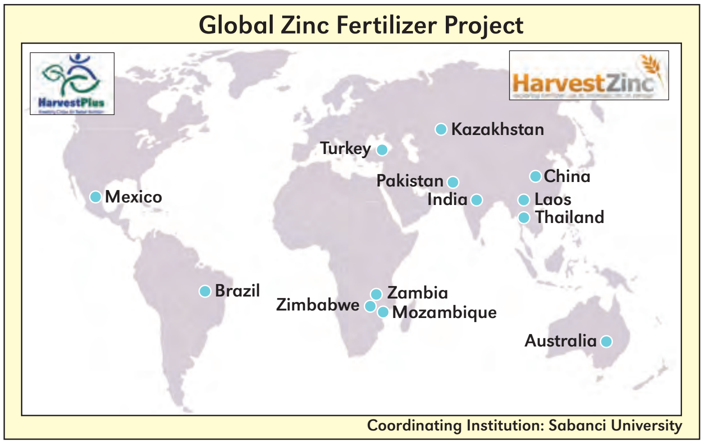

Figure 2. The countries where Zn fertilizers trials are conducted.

Agronomic biofortification (application of Zn fertilizers) represents a quick approach to the problem. Enrichment of cereal grains through application of Zn fertilizers promises to be a relevant and practical approach to improve Zn concentrations of staple food crops. Agronomic biofortification is essential for keeping sufficient amount of available Zn in soil solution (by soil Zn applications) and in leaf tissue (by foliar Zn applications) which greatly contribute to maintenance of adequate root Zn uptake and transport of Zn from leaf tissue to the seeds during reproductive growth stage. This approach is also required for ensuring the success of biofortification of food crops with Zn through use of breeding tools.

HarvestPlus Zinc Fertilizer Project: HarvestZinc

HarvestPlus Zinc Fertilizer Project, called HarvestZinc is exploring the potential of various Zn-containing fertilizers for increasing Zn concentration of cereal grains and improving yield in different target countries such as India, China, Pakistan, Thailand, Laos, Turkey, Zambia, Mozambique, and Brazil (see www.harvestzinc.org). The program is coordinated by Sabanci University in Istanbul (**Figure 2**).

Based on the results obtained within the 1st Phase of the project (2008 to 2011), the reaction of cereal crops to Zn fertilization showed large variation between the countries and even within a given country in terms of grain yield response. Increase in grain yield upon Zn applications ranged between 0 to 22%. In some locations in India, Pakistan and Turkey, wheat grain yield was increased up to 22% by soil Zn applications. In contrast to the large variations in grain yield among countries and even within a given country, the results with grain Zn

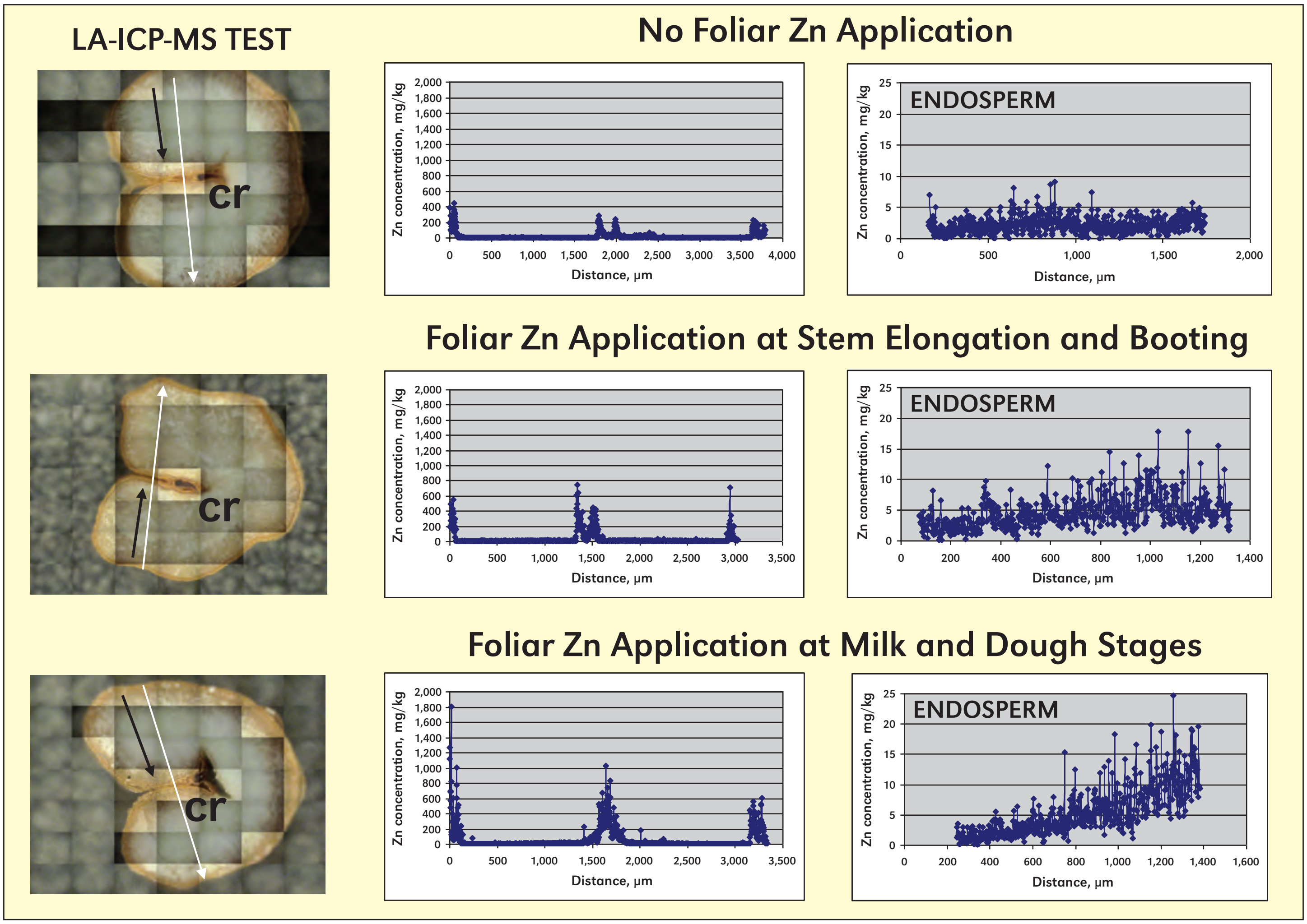

Figure 3. Changes in Zn concentrations of the endosperm part of wheat seeds from plants which were treated by $ZnSO_4$ at different growth stages under field conditions. Changes in Zn concentration were measured by using LA-ICP-MS (Laser Ablation Inductively Coupled Plasma Mass Spectrometry). Black arrow on seeds (left side) shows the studied area on endosperm. White arrow shows the studied area on the entire cross section. Distance on the x-axis represents the length of the studied section (places) on the seeds that are shown with the black or white arrows. For more detail see: Cakmak et al., 2010.

Zinc Day events held in Pakistan (top) at Faisalabad and China (bottom) at Weinan-Xian.

concentrations were highly consistent. Grain Zn concentrations were significantly increased by foliar Zn applications while soil Zn application was less effective. Among wheat, rice and maize, wheat has been found to be the most promising cereal crop for increasing Zn in grains through foliar Zn fertilization. In this aspect, maize appears to be less responsive. In case of wheat, particular increases in grain Zn concentration after foliar application of Zn were observed in each country (an average of about two-fold).

The trials also showed that the timing of foliar Zn application is a critical issue in maximizing grain Zn concentration (Cakmak et al., 2010). According to the results obtained from several field tests, foliar spray of Zn late in growing season resulted in much greater increases in grain Zn concentration when compared to the earlier foliar applications of Zn (**Figure 3**). Increases in concentration of whole grain Zn through foliar Zn applications were also well reflected (proportionally) in all grain fractions analyzed, especially in the endosperm, the part predominantly consumed in food products in target countries.

Another important finding in the past 3 years under the HarvestPlus Zinc Fertilizer Project was related to the role of N nutrition in enriching cereal grains with Zn (and also Fe). Nitrogen-nutritional status of plants appears to be a very critical factor in: i) root uptake, ii) root-to-shoot translocation, and iii) grain accumulation of Zn and Fe (Kutman et al., 2011; Aciksoz et al., 2011). Increasing N supply very positively affected root uptake, shoot translocation and grain deposition of Zn.

New Tasks and Challenges

Based on evidence that foliar Zn application is highly effective and promising in doubling grain Zn concentration at any location tested, for example in wheat, it is important to motivate and encourage farmers to spray Zn to increase grain Zn as well as grain yield. The following strategies can be employed for motivation (and encouragement) of farmers to spray Zn unless there is no Zn deficiency problem in soils:

- to demonstrate that plants emerging from high Zn-seeds: i) have improved seedling vigor and hence ii) better yield (besides human nutritional effects);
- to evaluate the applicability of Zn together with widely used insecticides and/or fungicides on wheat and rice in the target countries.

Applying Zn-containing compound fertilizers into soil will ensure a better and healthy root system and maintain high amounts of plant available Zn pools in growth medium which will significantly contribute to enhanced root uptake of Zn. In the second phase of the project (2011 to 2014), special attention will be paid to these tasks for motivation of farmers to include Zn in their soil and foliar fertilization programs.

Zinc Day Events

Delivery of the project results to farmers (end-users) is a vital issue for the success of the project. One of the major goals of the second phase of the HarvestZinc project is, therefore, to promote and disseminate the practical and theoretical knowledge and experiences gained during the project. An important attention is being paid to the organization of ***Zinc Days*** in the target countries for the agronomists/crop consultants, extension staff, farmers and decision makers at the different stages of the project to increase awareness of the importance of Zn nutrition in human health and crop production. BC

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Int'l Fertilizer Industry Association, France	International Plant Nutrition Institute, USA
Bayer CropScience, Germany	ADOB, Poland
Valagro, Italy	FBSciences, USA
ATP Nutrition, Canada	

The HarvestZinc project is coordinated by Sabanci University and realized together with the collaborating partners given below:	
Brazil: Instituto Agronomica, Campinas	China: China Agricultural University, Beijing
India: Punjab Agricultural University, Ludhiana	Pakistan: Pakistan Atomic Energy Commission (PAEC), Islamabad
Thailand: Chiang Mai University	Turkey: Ministry of Agriculture
Zambia: Golden Valley Agricultural Research Trust, Lusaka	

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Great Plains Soils May be C Sinks

By David E. Clay, Gregg C. Carlson, Sharon A. Clay, James Stone, Kurtis D. Reitsma, and Ronald H. Gelderman

Numerous studies with wide-ranging results have been conducted to resolve if Great Plains soils are a C source or sink. The authors addressed the source/sink question by examining the results from producer soil samples and production surveys that were analyzed and archived by the South Dakota Soil Testing Laboratory. Results showed that between 1985 and 2010, soil organic C content increased at a rate of 326 lb C/A/year, for a total increase of 24%. The increase was attributed to planting better adapted varieties and using better management practices that on average increased corn grain yields 2.29 bu/A/year. Higher soil organic C has impacts on water quality, soil productivity, and plant nutrition. For example, if we assume that the C:N ratio of organic matter is 10:1, then these findings would indicate that soils during this 25-year period were a sink for both C and N, and could have influenced the N needed to optimize crop yields.

Life-cycle-analysis (LCA) methodology is being used to determine the C footprint of agricultural products through cradle-to-grave environmental accounting (Clay et al., 2006; Wang et al., 2007; Wang 2008; Liska et al., 2009; Plevin, 2009, Carlson et al., 2010). The power of the LCA approach is that different products can be compared quantitatively and independently. For example, typical C footprints for coal, gasoline, and grain-based ethanol have been reported to be 134, 96, and 65 g CO_2eq/MJ (Liska et al., 2009), respectively. These values are influenced by many factors including production requirements, shipping distance, and manufacturing inputs. In these calculations, soil C sequestration is often not considered, or it is considered as a C source, thereby adding to the C footprint.

Common Abbreviations and Notes: N = nitrogen; C = carbon; SOC = soil organic carbon; CO_2eq/MJ = carbon dioxide equivalents per Mega Joule.

The fate of soil C is influenced by many factors ranging from tillage intensity to the amount of non-harvested C (NHC) returned to the soil (Clay et al., 2006, 2010). In agriculture, our ability to calculate accurate footprints has been limited by the availability of accurate SOC benchmarks. One source of benchmark information is producer soil samples that were analyzed for by public and private laboratories. These laboratories generally follow strict analytical protocols and the analysis results are often archived. These laboratory databases can contain many thousands of analyses and associated production surveys. Using South Dakota soil testing laboratory databases, this study's objective was to determine if eastern South Dakota soils are C sources or sinks. The study used 95,214 surface

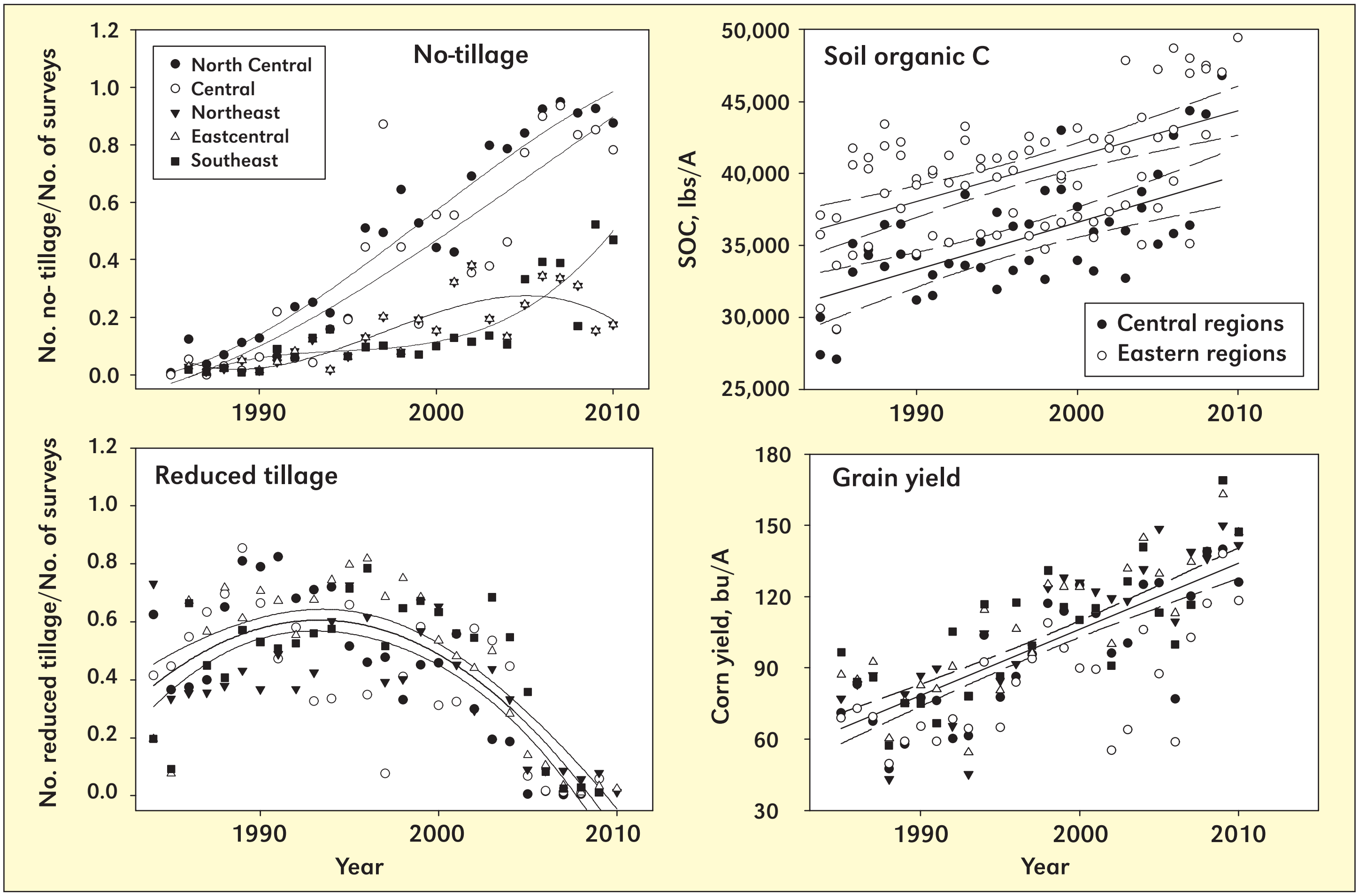

Figure 1. The influence of year and 5 sampling regions on no-tillage adoption, average corn grain yields, and soil C storage. In these graphs, the relative use of no-tillage, SOC, and grain yields are shown.

soil samples and 74,655 production surveys collected between 1985 and 2010.

Carbon Source or Sink

The temporal SOC changes in producer soil samples indicates that over the past 25 years, surface 6-in. SOC amounts have increased at a rate of 326 lb C/A/year (**Figure 1**). These results were attributed to at least three factors. The first factor is the gradual yield increase of 2.29 bu/A/year, which also increased the amount of NHC returned to soil (Allmaras et al., 2000). For example, a 10 bu/A yield increase results in an additional 380 lb C/A returned to soil annually. The second factor is the adoption of reduced, minimum, and no-tillage farming systems. Rapid no-tillage adoption rates are attributed to improved planting equipment, and genetically modified crops that improved and simplified pest management. The third factor is over 100 years (from the late 1900s to the late 20th century) of intensive tillage that reduced native soil organic matter contents from 40 to 60%.

Simulation analysis was used to assess if these factors could account for temporal changes in SOC. This analysis showed that the gradual but constant yield increases over this long period of time in combination with reduced tillage could result in periods of time where the soil behaved as a C source and then a C sink (**Figure 2**). The decrease in SOC values following the initial breaking of the prairie sod is consistent with historical records. Based on values from Puhr and Olsen (1937), and those in this report, it is estimated that 42% and 60% of the SOC contained in the 1880s soil was lost by 1937 and 1985, respectively. These findings are in agreement with Allmaras et al. (2000).

Our analysis suggests that the switch from source to sink occurred in the 1980s and 1990s. Since Allmaras et al. (2000), no-tillage adoption in the glaciated regions of South Dakota increased from <10% in 1998 to a regional average of 44% in 2004 and 2007 with some regions having near 100% no-till adoption. In addition, average South Dakota corn grain yields increased from 84 bu/A in 1985 to 135 bu/A in 2010. This 51 bu/A increase resulted in more C (2,000 lbs C/A) being returned to the soil.

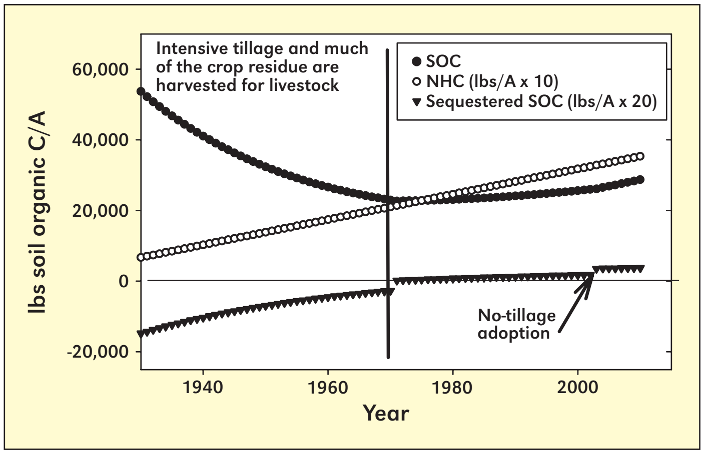

Figure 2. Simulated temporal changes in SOC resulting from conservation and no-tillage adoption and increasing amount of non-harvested C (NHC) returned to soil. In this chart, NHC is multiplied by 10, while sequestered C is multiplied by 20.

Partial Carbon Footprints

A simulation model was used to determine the SOC sequestration potentials and associated partial C footprints for 5 corn-growing regions in South Dakota (**Table 1**). Corn grain yields for the 2004 to 2007 and 2008 to 2010 time periods were obtained from NASS (2011). Sequestered C was converted to g CO_2eq/MJ using appropriate calculations (Clay et al., 2012). When soil functions as a C sink rather than a source, C sequestration can have a large impact on C footprints. The calculations showed that the partial C footprints associated with corn production ranged from -5.1 to -14.9 g CO_2eq/MJ for the time period between 2004 and 2007 (**Table 1**). Slightly higher C sequestration potentials (more negative footprint) were observed between 2008 and 2010. This more negative footprint was attributed to higher yields and larger amounts of NHC returned to the soil.

Carbon sequestration can have a huge impact on the calculated LCA footprint for an ethanol plant. For example, if a surface soil has a C sequestration potential of -15.4 g CO_2eq/MJ (average value from 2008 to 2010) rather than not being considered, then the C footprint for an ethanol plant with a previously determined footprint of 58 g CO_2eq/MJ would now be determined to be 42.6 g CO_2eq/MJ. This value would meet the proposed California advanced fuel standard (Arons et al., 2007). If the 58 CO_2 eq contained a value for soil being a C source, this modified footprint could be even lower.

Currently, most corn-based ethanol LCA calculations do not consider soil as a C sink (Mueller and Unnasch, 2007; Wang, 2008; Liska et al., 2009). For example, Wang (2008) considered corn production as a C source (+0.9 g CO_2eq/MJ), whereas switchgrass was treated as a C sink (-6.73 g CO_2eq /MJ). This research suggests that annually cropped South Dakota surface soils under current management practices should be treated as a C sink. Additional research is needed to expand this conclusion to other regions. Archived information obtained by soil testing laboratories may provide information needed to quantify change.

In summary, analysis suggests that C is being sequestered in many Northern Great Plains surface soils. These results are attributed to: 1) SOC mining that occurred following homesteading, 2) gradual crop yield increases, which increased NHC returned to soil; and 3) wide scale adoption of reduced tillage and then no-tillage. Others have reported similar results

Table 1. The influence of South Dakota NASS sampling region and calculated short-term sequestered C rates on partial C footprints for the 2004 to 2007 and 2008 to 2010 time periods.

	-------- 2004 to 2007 --------		-------- 2008 to 2010 --------	
	Sequestered C	Partial C footprint	Sequestered C	Partial C footprint
	lbs SOC/A/yr	g CO_2eq/MJ	lbs SOC/A/yr	g CO_2eq/MJ
North-central	205	-14.9	369	-19.6
Central	62	-5.10	295	-14.8
Northeast	163	-8.86	207	-12.0
East-central	113	-6.31	236	-11.4
Southeast	203	-14.9	406	-19.2

(West and Post, 2002; Allmaras et al., 2000). The difference between this study and previous study is that this study used benchmarks from producer fields to document improvements. These results are different than a general perception that annually cropped soils in the Northern Great Plains are losing C. These findings may have ramifications relative to water quality and soil resilience. This assessment provides an excellent example of how universities in collaboration with our federal and private industry partners can work together to enhance the economic and environmental well-being of the clientele we serve. BC

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IPNI Launches New Website

The International Plant Nutrition Institute has launched its new website, still accessible at http://www.ipni.net. The beautifully redesigned site, created by Brian Green, IPNI IT Manager, was planned with the international scope of IPNI and its subscribers in mind.

The site now has the ability to change content dynamically based on the user's language preference and location in the world. The site also features a much-improved Google search engine for more precise results. Most notably is the new modern design, with a more intuitive, topical based navigation. The homepage also has new categories for our most popular content; "News", "Research" and "Publications". Visit the site today and enjoy all of the improved features.

http://www.ipni.net

Optimizing Phosphorus and Manure Application in Maize-Soybean Rotations in Zimbabwe

By Shamie Zingore and Ken E. Giller

Soybean production in Zimbabwe is limited because farmers give little attention to the crop and prefer to apply fertilizer to the previous crop in the rotation (maize). Our research showed that the combined application of P fertilizer and manure to maize, as is currently practiced by farmers, was more productive and economic under poor soil fertility conditions. However, there is potential to increase income with application of P and manure to soybean on more fertile soils.

Cultivation of maize as a monocrop with little addition of nutrients has contributed to depletion of soil fertility on smallholder farms in sub-Saharan Africa. Soybean varieties with low N harvest indices are commonly promoted for use in small holder farming systems in Africa and have great potential to contribute N to soil through biological N_2-fixation (BNF), while improving the income and nutrition of smallholder farmers (Mpepereki et al. 2000; Giller and Cadisch 1995). However, major challenges exist to enhance the productivity of soybean and other grain legumes under smallholder farm conditions (Snapp et al. 2002). Soils cultivated by smallholder farmers are predominantly infertile and sandy, with low levels of available P. Other factors constraining production of grain legumes are directly linked to farmers' preference to use fertilizer on maize while growing the crop on the most fertile soils (Zingore et al. 2007). Production of grain legumes on poor soils, and with residual fertility, has led to very poor yields (< 0.5 t/ha) and low N_2 fixation (< 5 kg N/ha/yr) (Giller 2001).

This study investigated two key questions related to the effects of farmer management practices on productivity of grain legumes and maize: i) What is the effect of soil fertility status on productivity of soybean and the crop response to P fertilizer? and ii) Is the current practice of targeting nutrient resources to maize and growing grain legumes on residual fertility more productive and economic than targeting nutrients to grain legumes?

Two on-farm experiments were conducted for 3 years (2004 to 2007) in northeast Zimbabwe, a site with a high potential for crop production (i.e. 850 mm avg. annual rainfall). The dominant soils in the area are either infertile sandy soils derived from granite, or more fertile red clay soils derived from dolomitic parent materials. The first experiment was a multi-location experiment to assess soybean response to P fertilizer across fields varying in soil fertility. The experiment was established in 50 fields covering a wide range of soil fertility conditions and textures (sandy to clayey soils). On each field, two plots (5 m x 5 m) were marked out with the following treatments: i) soybean without nutrient inputs; and ii) soybean fertilized with 30 kg P/ha as SSP. All plots were analyzed for soil organic C and available P using the Olsen method.

The second experiment was conducted on two fields: i) sandy soil (3% clay, 5% silt, and 92% sand) with 0.3% SOC, 3 mg/kg available P (Olsen), pH of 4.5 and 3.9 using water and $CaCl_2$, respectively, and CEC of 2 $cmol_c$/kg; and ii) a more fertile red clay soil (34% clay, 18% silt, and 48% sand) with 0.9% SOC, 12 mg/kg available P (Olsen), pH of 5.6 and 4.9 with water and $CaCl_2$, respectively, and CEC of 16 $cmol_c$/kg. At both these sites, soybean and maize were planted in a two-course rotation for three seasons: soybean-maize-soybean for the rotation in which soybean was grown in the first season, and maize-soybean-maize where maize was grown in the first season (**Table 1**). Cattle manure and SSP were applied to crops in the first and third season, while residual effects were assessed in the second season. Control treatments included soybean and maize grown as monocrops.

Single superphosphate was applied at 30 kg P/ha—the regional recommendation for maize. Manure was also applied to provide 30 kg P/ha. Soybean residues were incorporated in the top 20 cm after harvest in the first season. Maize residues were removed, as farmers use the residues for cattle fodder. All the maize plots, except the monocrop control, received 70 kg N/ha applied as ammonium nitrate at about 3 and 6 weeks after emergence. The experiment at each site was set up in a randomized complete block design with three replicates. Data collected for the second experiment included grain and residue yields, N and P contents of grain and residues, and N_2-fixation was estimated using the ^{15}N natural abundance method. The proportion of N fixed by soybeans was calculated as the percentage of total N fixed over total N accomodated

Common abbreviations and notes: N = nitrogen; P = phosphorus; C = carbon; Ca = calcium; Mg = magnesium; Mo = molybdenum; Co = cobalt; SSP = single superphosphate; CEC = cation exchange capacity; SOC = soil organic carbon; $CaCl_2$ = calcium chloride.

Table 1. Experimental treatments for analysis of effects of SSP and manure in soybean/maize rotations.

Treatment	First season	Second season	Third season
1	Soybean	Soybean	Soybean
2	Soybean	Maize + 70 kg N/ha	Soybean
3	Soybean + 30 kg P/ha (SSP)	Maize + 70 kg N/ha	Soybean + 30 kg P/ha (SSP)
4	Soybean + 14 t manure/ha	Maize + 70 kg N/ha	Soybean + 14 t manure/ha
5	Maize	Maize	Maize
6	Maize + 70 kg N/ha	Soybean	Maize + 70 kg N/ha
7	Maize + 30 kg P/ha (SSP) + 70 kg N/ha	Soybean	Maize + 30 kg P/ha (SSP) + 70 kg N/ha
8	Maize + 14 t manure/ha + 70 kg N/ha	Soybean	Maize + 14 t manure/ha + 70 kg N/ha

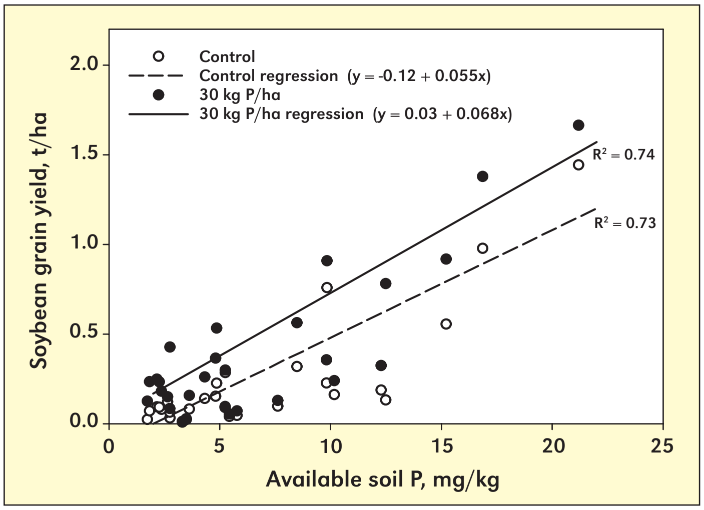

Figure 1. Relationships between soil available P and soybean yields for P fertilized and unfertilized crops.

Field experiments comparing the effects of P application in maize and soybean production in eastern Zimbabwe. Dr. Shamie Zingore, on the left, alongside the cooperating farmer.

Table 2. Average yields of soybean and maize as affected by direct P and manure application in the first and third seasons, northeast Zimbabwe.

		First and third season yield, t/ha	
Treatment	Crop	Sandy soil	Clay soil
1. Control soybean - sole crop	S	0.16	0.57
2. Control soybean - rotation	S	0.15	0.59
3. Soybean + 30 kg P/ha (SSP)	S	0.26	0.79
4. Soybean + 14 t manure/ha	S	0.52	1.18
5. Control maize - sole crop	M	0.44	2.18
6. Control maize rotation + 70 kg N/ha	M	0.64	2.26
7. Maize + 30 kg P/ha (SSP) + 70 kg N/ha	M	1.32	2.92
8. Maize + 14 t manure/ha + 70 kg N/ha	M	2.53	3.41
SED*		(0.05^S; 0.32^M)	(0.06^S; 0.38^M)

*Standard error of difference for comparison of treatment effects on soybean (S) and maize (M) yields.

Table 3. Residual effects of SSP and manure on soybean and maize in the second season, northeast Zimbabwe.

		Second season yield, t/ha	
Treatment	Crop	Sandy soil	Clay soil
1. Control soybean - sole crop	S	0.23	0.49
2. Control maize - rotation + 70 kg N/ha	M	0.73	2.42
3. SSP residual effects - maize + 70 kg N/ha	M	1.13	2.77
4. Manure residual effects - maize + 70 kg N/ha	M	1.78	2.63
5. Control maize - sole crop	M	0.42	1.84
6. Control soybean - rotation	S	0.21	0.42
7. SSP residual effects - soybean	S	0.29	0.73
8. Manure residual effects - soybean	S	0.54	0.79
SED*		(0.08^S; 0.18^M)	(0.09^S; 0.22^M)

* Standard error of difference for comparison of treatment effects on soybean (S) and maize (M) yields.

in grains and residues. The economic benefits of using SSP and manure in maize/soybean rotations were calculated by subtracting the field value of the output from the field value of inputs (fertilizers and seed).

Soil Available P and Soybean Yields

Soil P levels in farmers' fields were 2 mg/kg and up, and more than 90% of fields had available P status below the critical level of 15 mg/kg in experiment 1. The yields of soybean, and their response to P, were strongly correlated with available P (**Figure 1**). Without P application, soybean yields of < 0.5 t/ha were found in fields that had less than 12 mg/kg available P. With P application, soybean yields increased from 0.5 t/ha in soils with < 5 mg/kg available P to about 1.6 t/ha in soil with the highest available P. The results confirm the low soybean productivity on poor soils, which farmers commonly allocate for soybean production. Still the maximum yields observed are far below the attainable yield for soybean under similar agro-ecological conditions (i.e. 3 to 4 t/ha; Kasasa et al. 1999), possibly due to other limiting nutrients.

Crop Yields

In experiment 2, unfertilized soybean and maize grain yields were low on the infertile sandy soil (**Table 2**). Direct application of SSP led to a marginal increase in soybean yields, but yields were significantly increased (> 300%) with manure application. Maize yield response was also poor with only N fertilization in the first season, but increased with both N and P fertilization. But the largest maize yields were obtained in plots where manure and mineral N fertilizer were applied. For clay soil, yields for all treatments without amendments were significantly higher than in the sandy soil for all seasons. Soybean yields were significantly increased by the addition of either SSP or manure in the clay soil. Maize grain yields for fertilized plots in the first and third seasons decreased in the order N+manure > N+SSP > N alone.

Nitrogen Contents and N_2-Fixation

The total amount of N accumulated by soybean grown on sandy soil without any fertilizer input was very small (< 15 kg N/ha; data not shown). On plots where SSP was applied, total N content in soybean grain and residues averaged 20 kg/ha for the first and third seasons, but increased significantly with manure application. Also, the proportion of N_2 fixed by soybean when manure was applied was significantly higher (83%) than the values obtained for soybean grown without amendments or with application of SSP (61 to 64%) (data not shown). Among soils, the amount of N in soybean biomass was higher on the clay soil than on the sandy soil. For the first and third seasons, when manure and SSP were directly applied, the largest amounts of N were accumulated in plots with manure application (75 kg N/ha on average) followed by SSP application (53 kg N/ha on average), and were least on the plots without any amendment (28 kg N/ha on average). The proportion of soybean N derived from the N_2-fixed on clay soil was greater than 65% across all seasons.

Residual Effect on Crop Yields

On sandy soil and in the second season, maize grain yields following soybean grown without any amendments was only 0.31 t/ha greater than the continuous maize plots, despite application of 70 kg N/ha to the maize following soybean (**Table 3**). Manure applied in the first season led to strong residual effects in the second season resulting in higher maize and soybean yields. Maize grain yields on clay soil in the second season were least on the plots where maize was cropped continuously without fertilizer inputs. Manure or SSP applied to maize in the first season led to significantly greater soybean yields in the second season than those for soybean following maize that had received N fertilizer alone. However, soybean yields on the clay soil were lower when grown with residual fertility (second season) than with direct application of manure in the first and third seasons.

Gross Margins

The gross margins from maize and soybean without fertilizer inputs were small on the granitic sandy soil (**Table 4**). Greatest economic benefits for both maize and soybean were obtained with manure. Maize was more profitable than soybean when manure or SSP were applied, despite the extra cost of mineral N added to maize. Overall, gross margins for the three seasons for unfertilized soybean and maize monocrop plots did not differ substantially with rotations without addition of P, which were also small due to poor yields. On the sandy soil, addition of manure to the maize crop led to greater gross margins within the rotation than its addition to the soybean crop, whilst the differences for SSP were marginal. On the clay soil, gross margins were higher for maize than soybean when the crops were grown continuously without fertilizer inputs (**Table 4**). However, within rotations gross margins for the treatment in which manure or SSP were applied to soybean was substantially greater than when applied directly to maize.

The limited productivity and response of soybean to P application on the sandy soil could have been due to a deficiency of Ca, Mg, and/or other micronutrients such as Mo and Co, which are essential for N_2-fixation (Giller, 2001). The soils were also acidic and contained small amounts of organic matter, conditions that are not favorable for soybean production.

Summary

Degraded sandy soils are widespread in Africa and these soils cannot support soybean production without proper fertilizer management. On such soils, current farmer management of applying fertilizer and manure to maize is more viable. The substantial increase in yields and proportion of N_2 fixed with direct application of manure was due to its multiple effects such as supplying multiple secondary and micronutrients, improving moisture availability, and increasing soil pH (De Ridder and Van Keulen 1990). However, low manure availability is a major challenge that limits its wide-scale use to improve crop productivity.

On the clay soil, direct application of manure and SSP to soybean in the first and third seasons led to greater returns than direct application to maize, and this led to the higher returns for the 3-year rotations when SSP and manure were applied to soybean. There are opportunities, therefore, for farmers on the more fertile soils to increase income by targeting manure to soybean rather than maize (Chikowo et al. 1999; Okogun et al. 2005). To maximize benefits from legume production, smallholder farmers need to focus attention on the more fertile plots, although production should be optimized in relation to maize. Longer-term sustainable intensification of maize/soybean systems may however require increased fertilizer use which would allow applying fertilizer directly to each crop, as well as addressing multiple nutrient deficiencies limiting yields on poor soils. BC

Table 4. Gross margin analysis for targeting P and manure with soybean/maize rotations in northeast Zimbabwe.

	Gross margins*, USD/ha	
Treatment	Sandy soil	Clay soil
1. Control soybean - sole crop	176	848
2. Control soybean - rotation	204	1,083
3. Soybean + 30 kg P/ha (SSP)	357	1,213
4. Soybean + 14 t manure/ha	732	1,712
5. Control maize - sole crop	209	1,084
6. Control maize - rotation + 70 kg N/ha	148	891
7. Maize + 30 kg P/ha (SSP) + 70 kg N/ha	309	1,187
8. Maize + 14 t manure/ha + 70 kg N/ha	955	1,413

*The costs (USD; averaged for three years) of inputs were: SSP = $2.25/kg P; manure = $2.25/kg P; ammonium nitrate = $1.35/kg N; maize seed = $0.74/kg; soybean seed = $0.96/kg. Grain prices were $300/t for maize and $753/t for soybean.

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Fertilization of High Density, Rainfed Cotton Grown on Vertisols of India

By Jagvir Singh, Shilpa Babar, Shalu Abraham, M.V. Venugopalan, and G. Majumdar

Despite large tracts of irrigated cotton, rainfed systems remain the most important option for improving cotton production in India. Within rainfed fields, the potential effects of adopting high plant population with adequate NPK fertilizer management offer a good opportunity to increase crop productivity.

India has the largest area in the world under cotton at 10.1 M ha and is the second largest producer in the world at 31 M bales. However, India's average cotton productivity is 478 kg lint yield /ha, combining both irrigated and rainfed fields, and this is low compared to other countries like China (1,311 kg lint/ha), Brazil (2,027 kg lint/ha), U.S. (945 kg lint/ha) as well as the world average yield of 763 kg lint/ha (ICAC, 2011).

Rainfed cotton occupies 7 M ha (70%) with an average productivity of 230 kg/ha in India. The majority (90%) of cotton in the State of Maharashtra is rainfed, and this area is expected to increase in the coming years. A system of high density planting (HDP) leading to more rapid canopy closure and decreased soil water evaporation, is becoming popular to address water scarcity challenges. In many countries, narrow row plantings have been adopted after showing improvement in cotton productivity (Ali et al., 2010). The adoption of HDP, along with good fertilizer management and better genotypes, is a viable approach to break the current trend of stagnating yields under primarily rainfed *hirsutum* (upland) cotton growing areas.

Experimental Sites and Design

Four sites (Nagpur, Akola, Parbhani, and Nandyal) were selected during the *kharif* (rainy) season of 2010-11. The commercial varieties grown at these sites included NH 615, NH 452, and PKV 081 at Nagpur, AKH 081, NH 615, and NH 630 at Akola, NH 545, NH 452, and AKH 081 at Parbhani, and NDLH 1938 at Nandyal. The varieties were sown at the onset of the monsoons during the last week of June at Nagpur and Akola, and in the second week of July at Parbhani and Nandyal. Each sub-plot contained ten rows of cotton, 5.4 m long. A plant spacing of 0.45 m x 0.15 m produced a high density population of 14.9 plants/m^2. The traditional plant population is 5.5 plants/m^2.

In Maharashtra and Andhra Pradesh, the climate is hot, dry, and sub-humid. Soils are dominated by Vertisols and Vertic intergrades. Soils at the experimental sites were medium deep black, slightly alkaline (pH 7.8 to 8.4), low-to-medium in available N and P, and high in K status (**Table 1**).

A split-plot design with three replications was used with the main plots being three upland varieties and the subplots being four levels (75, 100, 125, and 150% RDF) of NPK fertilizers. Data were collected for seed cotton yield, yield components, and biological yield. Total heat unit during the crop period was estimated on the basis of weekly maximum and minimum temperatures using this equation:

Total Heat Unit=(Max.Temp+Min.Temp)÷2 - Base Temp. (15 °C)

Common abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; C = carbon; RDF = recommended dose of fertilizer; GR = Gross returns; NR = net returns; B:C ratio = benefit:cost ratio; M = million.

Table 1. Physiochemical properties of selected soils and their respective fertilizer recommendations (100% RDF).

Particulars	Nagpur	Akola	Parbhani	Nandyal
Clay, %	53	48	54	50
Available N, kg/ha	111	218	116	127
Available P_2O_5, kg/ha	18	23	26	87
Available K_2O, kg/ha	481	365	675	591
Organic C, g/kg	3.5	3.7	4.1	4.0
100% RDF, N:P:K	60:13:26	50:20:0	84:18:36	40:9:18

Available N, P_2O_5, and K_2O values reported were determined using the Kjeldahl, Olsen, and 1 N ammonium acetate extraction methods, respectively.

Results and Discussion

Seed cotton yield varied greatly among locations (**Table 2**). Mean seed cotton yield recorded at Nandyal was 13% more than the yield obtained at Akola and >70% higher than yields obtained at Nagpur and Parbhani. From the last week of June through the last week of December (the growing period of cotton), the observed average maximum and minimum temperatures were 30.2 and 21.1 °C at Nagpur, 32.2 and 21.2 °C at Akola, 31.1 and 20.3 °C at Parbhani, and 31.6 and 22.8 °C at Nandyal, respectively. Precipitation was high in the months of July and August at Nagpur and Parbhani, which reduced the growth and yield components. Precipitation during the period from flowering to early boll development (65 to 100 days after planting) is crucial for rainfed cotton. This amount was 339, 225, 222 and 198 mm at Parbhani, Akola, Nagpur, and Nandyal, respectively. During the crop period, Nandyal recorded higher heat units (360.5 °C) as compared to Akola (350.5 °C) and Parbhani (324.1 °C), which might have led to the differences in yields among locations.

No significant difference in seed cotton yield was found between the three varieties used at Nagpur, Akola, and Parbhani. However, variety NDLH 1938 recorded highest yield with the highest bolls per square meter (139.8 BPM) compared to NH 630 (125.5 BPM) under HDP. Seed cotton yield and yield components like plant height, bolls, sympodia, and biomass of upland cotton were increased by 125% NPK fertilization at all four locations. Seed cotton yield recorded with 125 and 150% RDF were significantly higher than that with 75% and 100% RDF. This indicates that fertilizer requirement is most likely to be higher under HDP (Jost and Cothren, 2000; Ali et al., 2007). Interaction effects between main plot and sub plot treatments were not significant for yield and BPM at all the locations.

Total nutrient (N, P, and K) uptake per hectare was higher

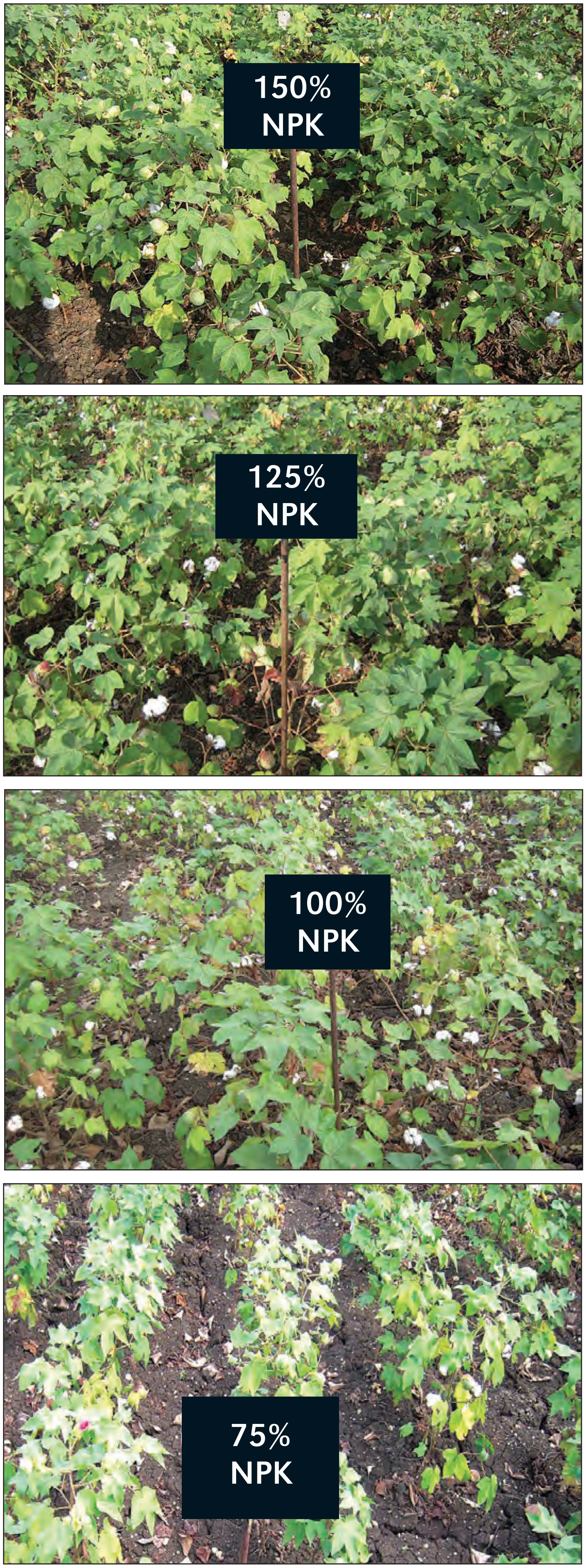
Table 2. Seed cotton yield and yield attributes of cotton in HDP at four experimental locations.

Treatment	Plant height, cm	Sympodia/ plant	Biomass/ plant, g	Open bolls/m^2	Yield, kg/ha	Treatment	Plant height, cm	Sympodia/ plant	Biomass/ plant, g	Open bolls/m^2	Yield, kg/ha
Nandyal						Akola					
Variety (V)						Variety (V)					
Narasimha	59.3	11.0	36.0	116.7	1,848	AKH 081	66.2	15.4	53.7	93.9	1,731
Sivanandi	65.8	11.7	42.9	121.6	1,868	NH 615	65.6	16.4	51.9	100.8	1,819
NDLH 1938	69.6	14.0	44.7	139.8	2,511	NH 630	75.1	17.6	64.6	125.5	1,917
Mean	64.9	12.2	41.2	126.1	2,076	Mean	68.8	16.5	56.7	106.7	1,822
RDF (F: NPK)						RDF (F: NPK)					
75%	56.0	11.8	33.5	104.3	2,026	75%	65.0	15.9	51.4	104.4	1,698
100%	64.2	12.5	33.8	123.7	2,060	100%	68.2	16.4	54.3	103.5	1,796
125%	63.9	12.8	35.0	126.6	2,133	125%	69.9	16.6	57.8	113.8	1,921
150%	65.7	11.9	34.3	125.2	2,082	150%	72.1	17.0	63.3	112.9	1,873
LSD (0.05) V	9.3	NS	14.9	19.6	313.0	LSD (0.05) V	7.4	1.3	1.45	17.7	NS
LSD (0.05) F	8.3	2.0	2.1	NS	NS	LSD (0.05) F	3.7	NS	4.9	NS	117.0
Parbhani						Nagpur					
Variety (V)						Variety (V)					
NH 545	64.7	6.9	33.1	125.2	1,286	NH 615	71.0	14.5	46.7	96.4	1,156
NH 452	61.5	6.6	31.5	116.2	1,221	NH 452	67.2	16.0	43.5	95.4	1,149
AKH 081	62.4	6.7	31.9	119.2	1,239	PKV 081	60.0	15.0	45.5	104.3	1,309
Mean	62.9	6.7	32.2	119.2	1,249	Mean	66.1	15.4	45.2	98.7	1,205
RDF (F: NPK)						RDF (F: NPK					
75%	59.4	6.4	30.4	119.2	1,179	75%	59.0	14.0	42.7	78.8	972
100%	60.9	6.5	31.2	123.7	1,210	100%	64.2	15.1	46.8	104.3	1,182
125%	67.5	7.2	34.6	125.2	1,341	125%	69.9	16.8	46.2	106.3	1,353
150%	63.6	6.8	32.6	129.6	1,263	150%	74.1	17.0	45.8	105.8	1,311
LSD (0.05) V	1.3	0.1	0.7	NS	NS	LSD (0.05) V	7.8	1.2	2.6	NS	NS
LSD (0.05) F	4.4	0.1	2.2	10.4	71.0	LSD (0.05) F	4.2	1.3	NS	20.1	136.0

Table 3. Nutrient requirement and economics of cotton at different NPK fertilizer levels.

NPK fertilizer levels	Yield, kg/ha	Nutrient uptake, kg/ha			Nutrient use per 100 kg yield, kg			Gross returns,* INR/ha	Net returns, INR/ha	B:C
		N	P	K	N	P	K			
Nandyal										
75%	2,026	101.5	17.6	124.9	5.0	0.9	6.2	100,700	75,700	4.02
100%	2,060	117.3	17.5	124.1	5.7	0.8	6.0	108,100	82,980	4.30
125%	2,133	122.4	19.0	120.5	5.7	0.9	5.6	108,750	83,510	4.30
150%	2,082	118.9	18.5	133.6	5.7	0.9	6.4	108,550	83,190	4.28
Akola										
75%	1,698	71.2	11.8	89.7	4.2	0.7	5.3	75,221	50,241	3.01
100%	1,796	78.8	13.8	99.3	4.4	0.8	5.5	79,563	54,055	3.12
125%	1,921	95.4	16.2	99.6	5.0	0.8	5.4	85,100	59,191	3.28
150%	1,873	84.6	18.7	103.9	5.1	1.0	5.5	82,974	56,423	3.12
Parbhani										
75%	1,179	53.0	12.9	79.6	4.5	1.1	6.8	56,599	35,155	1.64
100%	1,210	54.7	13.4	82.1	4.5	1.1	6.8	58,089	36,406	1.68
125%	1,341	60.2	14.7	88.2	4.5	1.1	6.6	64,373	42,450	1.94
150%	1,263	69.0	15.7	88.5	5.5	1.2	7.0	60,616	38,215	1.71
Nagpur										
75%	972	48.4	8.3	64.6	5.0	0.9	6.6	39,240	21,240	2.18
100%	1,182	65.1	9.6	85.0	5.5	0.8	7.2	48,690	30,290	2.65
125%	1,353	68.5	10.2	96.6	5.1	0.8	7.1	56,385	37,485	2.98
150%	1,311	70.3	9.9	94.6	5.4	0.8	7.2	54,540	35,140	2.81

*Cost of cotton cultivation for recommended practice (INR = Indian Rupee): Nandyal: INR 25,120/ha, Akola: INR 25,508/ha, Parbhani: INR 21,683/ha, and Nagpur: INR 18,400/ha. Cost of nutrients: INR 12/kg N, INR 7/kg SSP (single superphosphate), and INR 5.5/kg MOP (Muriate of Potash or Potassium Chloride) with higher NPK levels at all the four locations (**Table 3**). The nutrient use in upland cotton was high at Nandyal, which might explain higher seed cotton yield here compared to other locations. Plant P utilization was the least at Nagpur, which might have led to lower yield at this site. These results suggest high nutrient uptake is required for improved yield and numbers of bolls per m^2. The cotton plants had similar N and K uptakes (4.5 to 5.7 kg and 5.5 to 7.2 kg, respectively), while P uptake was 1.0 kg for every 100 kg seed cotton produced at all locations. Although plant nutrient uptake does not differentiate between soil and fertilizer sources, it does give some indication whether inadequate, sufficient, or excessive amounts of fertilizers were applied (Rochster et al., 2009). The higher requirement of NPK was attributed to higher seed cotton yield in HDP, which was needed to improve productivity of upland cotton (Jost and Cothren, 2000). As with the results for yields and nutrient uptake, maximum GR, NR, and B:C ratio were again recorded at 125% fertilizer application levels for Nandyal > Akola > Parbhani = Nagpur.



The trials on *hirsutum* cotton in high density plantings with NPK fertilization.

Summary

Cotton yields in upland, rainfed regions can be increased by higher plant populations that optimize numbers of bolls per plant and boll weight, while lowering cost of cultivation (as straight varieties of upland cotton require less fertilizer compared to hybrid cotton). Application of 25% more NPK fertilizer than the RDF within a 14.9 plant/m^2 stand achieved a maximum seed cotton yield. Cotton productivity can be improved through adequate fertilization of high-yielding, straight varieties of cotton suitable for high density planting. BC

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Fertilizing Crops to Improve Human Health: a Scientific Review

Editors: Tom Bruulsema, Patrick Heffer, Ross Welch, Ismail Cakmak, and Kevin Moran

A large proportion of humanity depends for its sustenance on the food production increases brought about through the application of fertilizers to crops. Fertilizer contributes to both the quantity and quality of the food produced. Used in the right way—applying the right source at the right rate, time and place—and on the right crops, it contributes immensely to the health and well-being of humanity.

Since 1948, the WHO has defined human health as "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity." The awarding of the 1970 Nobel Peace Prize to Dr. Norman Borlaug indicates a high level of recognition of the linkage of agricultural sciences to this definition of human health. This article summarizes an upcoming joint publication from IPNI and IFA comprised of 11 chapters in three volumes described below.

Volume 1: Food and Nutrition Security

Food security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food. Nutrition security means access to the adequate utilization and absorption of nutrients in food, in order to be able to live a healthy and active life (FAO, 2009). Between 1961 and 2008, the world's population grew from 3.1 to 6.8 billion. In the same period, global cereal production grew from 900 to 2,500 M t (**Figure 1**), with much of the growth due to the increase in world fertilizer use from 30 to over 150 M t. Without fertilizer use world cereal production would be halved (Erisman et al., 2008).

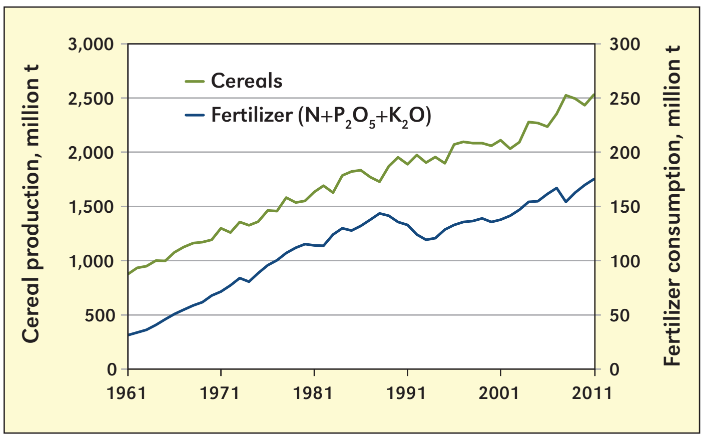

Figure 1. Global cereal production and total fertilizer consumption 1961-2011 (FAO 2012; IFA 2012).

By doubling the quantities of new N and P entering the terrestrial biosphere, fertilizer use has played a decisive role in making possible the access of humankind to food. However, not all have access. Chronic hunger still haunted the existence of one-sixth of the world's people in 2009. By 2050, according to FAO, the human population would require a 70% increase in global agricultural output compared to that between 2005 and 2007 (FAO, 2012). Future yield increases expected through genetic improvement will still depend on replenishment of nutrients removed by using all possible sources, organic and mineral, as efficiently as possible.

Common abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Ca = calcium; Mg = magnesium; Mn = manganese; Cu = copper; Fe = iron; Zn = zinc; I = iodine; Se = selenium; IFA = International Fertilizer Association; WHO = World Health Organization; M = million.

Nutrition Security. In addition to yield, plant nutrition affects other important components of human nutritional needs, including the amounts and types of carbohydrates, proteins, oils, vitamins and minerals. Many of the healthful components of food are boosted by the application of nutrients. Since most farmers already fertilize for optimum yields, these benefits are easily overlooked. Trace elements important to human nutrition can be optimized in the diet by applying them to food crops. Opportunity exists to improve yields and nutritional quality of food crops such as pulses, whose yields and production levels have not kept pace with population growth. Ensuring that such crops maintain economic competitiveness with cereals requires policies that reward farmers for producing the nutritional components of greatest importance to human health.

Micronutrient malnutrition has been increasing, partially as a consequence of increased production of staple cereal crops. Other micronutrient-rich crops, particularly pulses, have not benefited as much from the Green Revolution. Having become relatively more expensive, they now comprise a smaller proportion of the diets of the world's malnourished poor. Biofortification of crops can be an effective strategy for moving large numbers of people from deficient to adequate levels of Fe, vitamin A, and Zn. The choice of genetic or agronomic approaches to biofortification depends on the micronutrient. The two approaches can also be synergistic.

In staple crops, genetic approaches are most effective for Fe and vitamin A, while agronomic approaches including fertilizers can boost the Zn, I, and Se levels in foods. While deficiencies of I and Se do not limit the growth of plants, correction of Zn deficiency can benefit both crops and consumers of crops. Fertilizing cereals with Zn and Se improves both concentration and bioavailability of these trace elements. A large proportion—49%—of soils worldwide are considered deficient in Zn (Sillanpaa, 1990). The proportion of people at risk of Zn malnourishment, while varying regionally, is also substantial (**Table 1**).

Volume 2: Functional Foods

Calcium, Mg, and K are essential macro mineral nutrients for humans. The essential functions of these mineral elements in humans are similar to those in plants, with the striking exception of calcium's major role in bones and teeth. Their content in plants is influenced by their supply in the soil. Thus, in addition to assuring optimal crop production, fertilization practices may contribute to meeting the requirements for these

Table 1. Global and regional estimates of the proportion of the population at risk of inadequate Zn intake (Hotz and Brown, 2004).

Region	Population at Risk, %
N. Africa and E. Mediterranean	9
Sub-Saharan Africa	28
Latin America & Caribbean	25
USA and Canada	10
Eastern Europe	16
Western Europe	11
Southeast Asia	33
South Asia	27
China (+ Hong Kong)	14
Western Pacific	22
Global	21

minerals in human nutrition. Calcium deficiencies occur in countries where diets depend heavily on refined grains or rice (e.g. Bangladesh and Nigeria). Adequate Mg intake is not easily defined, but studies suggest a significant number of adults, even in the United States, do not consume adequate amounts. Similarly, a recommended daily allowance for K intake has not been defined, but only 10% of the men and less than 1% of women in the United States take in as much as or more than the adequate intake of 4.7 g/day.

Carbohydrates, proteins, and oils. Applying N to cereals adds to the protein they produce, as well as their yields. In rice, while N has its largest effects on yield, it can slightly increase protein and protein quality, since the glutelin it promotes has higher concentrations of the limiting amino acid, lysine, than do the other proteins it contains. In corn (maize) and wheat, protein may increase with N rates higher than needed for optimum yield, but the improvement in nutritional value may be limited by low concentrations of the essential amino acid lysine. An exception is the Quality Protein Maize developed by plant breeding: its lysine concentration remains high when more N is applied. In potatoes, N increases starch and protein concentration while P, K, and S enhance protein biological value. Oil composition of crops changes little with fertilization, though oil production is increased wherever yield-limiting nutrient deficiencies are alleviated.

Management tools that more precisely identify optimum source, rate, timing, and placement of N will help improve the contribution of fertilizer to production of healthful proteins, oils, and carbohydrates. Genetic improvements to N use efficiency may require careful attention to impact on protein quantity and quality in cereals. However, nutrient management practices such as late foliar applications or controlled-release technologies can boost N availability for protein production while keeping losses of surplus N to a minimum.

Health-functional quality of fruits and vegetables. Scientific evidence from numerous sources has demonstrated that judicious fertilizer management can increase productivity and market value as well as the health-promoting properties of fruits and vegetables. Concentrations of carotenoids (Vitamin A precursors) tend to increase with N fertilization, whereas the concentration of vitamin C decreases. Foliar K with S enhanced sweetness, texture, color, vitamin C, beta-carotene, and folic acid contents of muskmelons. In pink grapefruit, supplemental foliar K resulted in increased beta-carotene, and vitamin C concentrations. Several studies on bananas have reported positive correlations between K nutrition and fruit quality parameters such as sugars and ascorbic acid, and negative correlations with fruit acidity.

In addition to effects on vitamins, fertilizers can influence levels of nutraceutical (health-promoting) compounds in crops. Soybeans growing on K-deficient soils in Ontario, Canada had isoflavone concentrations about 13% higher when fertilized with K. Potassium has also been reported to promote concentrations of lycopene in grapefruit and in tomatoes. Broccoli and soybeans are examples of plants that can contribute Ca and Mg to the human diet.

When crops like these are grown in acid soils of limited fertility, applying lime can boost the levels of these important minerals. The potent antioxidant pigments lutein and beta-carotene, generally increase in concentration in response to N fertilization. Together with vitamins A, C, and E, they can help lower the risk of developing age-related macular degeneration, which is one of the leading causes of blindness.

Volume 3: Risk Reduction

Plant disease. In cereals deficient in Cu, ergot (*Claviceps sp.*) is an example of a food safety risk caused by a plant disease that can be controlled by application of Cu fertilizer. By immobilizing and competing for mineral nutrients, plant pathogens reduce mineral content, nutritional quality and safety of food products from plants. While many other specific diseases have known plant nutritional controls, there is a knowledge gap on the optimum nutrition for controlling the plant diseases most relevant to food safety. Managing nutrition influences diseases and their control. Strategies to reduce plant disease through plant nutrition include:

- the development of cultivars that are more effective in taking up Mn
- balanced nutrition with optimum levels of each nutrient
- attention to forms and sources suited to the crop (e.g. nitrate versus ammonium, chloride versus sulfate)
- timing, applying N during conditions favoring plant uptake and growth response
- integration with tillage, crop rotation, and soil microbes

Farming systems. Organic farmers apply strategies for plant nutrition that differ from those of other producers. Do these differences influence the healthfulness of the food they produce? Owing to the restricted sources for nutrient supply, organic farming cannot provide sufficient food for the current and growing population in the world. Also, because organic production systems rely heavily on ruminant animals and forage crops for the cycling of nutrients, the proportions of food types produced do not match the requirements of healthy diets. An imbalanced dietary composition can cause health problems as a result of insufficient supply of essential nutrients or excessive supply of other food constituents.

The composition of foods produced does show small changes explained by plant physiological responses to differences in N supply. Vitamin C is increased, but A and B vitamins, protein and nitrate are reduced under organic farming. Higher levels of nitrate in conventionally grown foods do not threaten and may be beneficial to human health. Despite the great interest in food quality among supporters of organic agriculture, focussing on food supply and dietary composition is most important for human health.

Remediating radionuclides. When soils become contaminated with radionuclides, as for example after accidents with nuclear reactors in Chernobyl or Fukushima, limiting plant uptake becomes an important goal for protecting human health. Studies on soils from the Gomel region of Belarus showed that levels of radiocaesium (^{137}Cs) and radiostrontium (^{90}Sr) in crops declined in response to increasing soil exchangeable K, with K applied as either fertilizer or manure. These radionuclide levels also declined with addition of dolomitic limestone, and N and P fertilizers. The involvement of rural inhabitants in processes of self-rehabilitation and self-development is a way to improve people's life quality on radioactive contaminated territories.

Summary

The foregoing demonstrates the very large role fertilizer plays in improving crop attributes relevant to the health of humankind.

Given the important role of fertilizers in promoting food and nutritional security, it becomes all the more important to invest in research aimed at optimizing the benefits associated with their use. Research needs to support the adoption of 4R Nutrient Stewardship ensuring that the right source is applied at the right rate, at the right time, and in the right place. This concept—embraced by the fertilizer industry—defines "right" as that most appropriate for addressing the economic, social, and environmental aspects of sustainability, all three of which are critical to sustaining human health. Coupled with appropriate strategic changes to farming systems toward production of a better balance of foods to address the true nutritional needs of the human family, an emphasis on 4R Nutrient Stewardship in agronomic research and extension will enhance the benefits and minimize the potential negative impacts associated with fertilizer use.

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Volume 1: T. Roberts and A. Tasistro - Food sufficiency: role of plant nutrition in supporting food security; H. Bouis, E. Boy, and J.V. Meenakshi - Micronutrient malnutrition: causes, prevalence, consequences and interventions; R. Welch and R. Graham - Perspectives on enhancing the nutritional quality of food crops with trace elements; G. Lyons and I. Cakmak - Agronomic biofortification of food crops with micronutrients. **Volume 2:** F. Nielsen - Calcium, magnesium and potassium in food; C. Grant and T. Bruulsema - Protein, oil and carbohydrate composition of foods; M. Oke and G. Paliyath - Fertilizer applications and nutraceutical content in health-functional foods; J. Jifon, G. Lester, W.M. Stewart, K. Crosby, D. Leskovar, and B. Patil - Fertilizer use and functional quality of fruits and vegetables; **Volume 3:** D. Huber - Plant nutrition and health risks associated with plant diseases; H. Kirchmann and L. Bergstrom - Human health issues associated with cropping systems; I. Bogdevitch, N. Mikhailouskaya, and V. Mikulich - Fertilization as a remediation measure on soils contaminated with radionuclides ^{137}Cs and ^{90}Sr.

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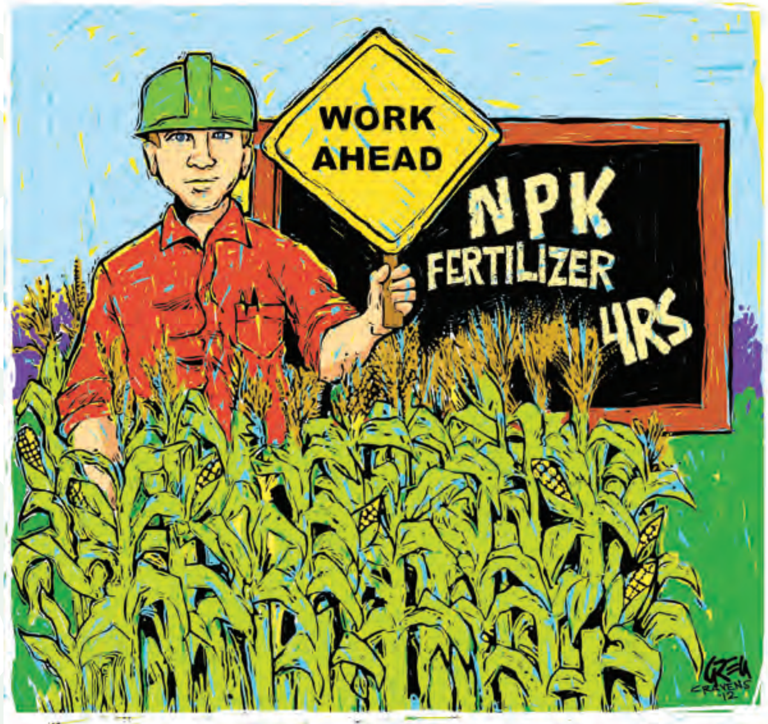
Symposium on Fertilizing for Crop Qualities that Improve Human Health ASA/CSSA/SSSA International Annual Meetings - Tuesday 23 October 2012

Sponsored by: SSSA Divisions S4 (Soil Fertility and Plant Nutrition) and S8 (Nutrient Management and Soil & Plant Analysis), International Fertilizer Industry Association (IFA), and International Plant Nutrition Institute (IPNI).

The World Health Organization defines human health as "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity." Agriculture produces foods that nourish human health. Sustainable fertilizer use must increasingly focus on the improvement of that health-sustaining role, towards a goal of healthy and productive lives for all in the context of a burgeoning world population.

We invite all participants of the ASA/CSSA/SSSA International Meetings in Cincinnati to attend this symposium, which will focus on the linkages between fertilizer use and crop attributes most closely connected to human health, exploring how the benefits can be optimized through 4R Nutrient Stewardship.

LOOKING BACK... THERE IS STILL WORK AHEAD



Situations change, but our problems and challenges often remain the same. A look back at several commentaries from the back cover of *Better Crops* confirms that.

In 2000, Dr. B.C. Darst, former Executive Vice President of IPNI's predecessor, the Potash & Phosphate Institute (PPI), wrote an article that questioned if agriculture and the fertilizer industry are there yet? Basically, the conclusion then—on whether our efforts have satisfactorily increased public awareness on the importance of adequate plant nutrition, and on whether we have made it clear that fertilizers are part of the solution to feeding an increasing population—was that we were not.

Two years later, Dr. Darst wrote another commentary on the back cover ...**Check out the Facts**.

This piece used an example from the media touting the benefits of organically produced food over those produced with "so-called" problematic chemicals. It demonstrated how readily people believe what they are told by the media without ever checking the facts.

In 2005, Dr. David W. Dibb, former President of PPI, wrote a back cover he titled, **May you live in interesting times**. This insightful piece pointed out how we presently live in rapidly changing times, with knowledge and opportunities to access information increasing daily, and that we, in agriculture, need to recognize each step forward has the potential to open doors in terms of production needs.

While we've seen progress over the last decade, as Agronomists, the message that much work remains ahead is still crucial to remember today as it was then. Our field of research was essential then and still is today.

We need to feed the world, we need to teach the public about the benefits of fertilizers, and we need to constantly push forward expanding our knowledge. It's no small task, but we have science on our side!

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