BETTER CROPS
WITH PLANT FOOD

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In This Issue...

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CONTENTS

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Tifton 85 Bermudagrass Response to Potassium Sources and Sulfur

By V.A. Haby, W.M. Stewart, and A.T. Leonard

Yield of Tifton 85 bermudagrass grown on a Coastal Plain soil in northeast Texas was significantly increased by the lowest K rate in this study in 2002 and 2003 and by a higher K rate in 2004. The response to higher K input over time was largely attributable to depletion of soil K in the first few years at the lower rate. Potassium sources and S initially had no effect on yield, but, over time, significant yield response to K, Cl, and S developed. Yield was optimized at the moderate N rate, but yields were further increased at the high N rate with greater K input.

'Tifton 85' bermudagrass (*Cynodon dactylon* (L) Pers.) is a relatively new hybrid with improved nutritive value and yield potential compared to established hybrids such as Coastal bermudagrass. Many studies have been conducted to determine the K requirements of Coastal bermudagrass. Adams and Twersky (1960) showed that high levels of available soil K reduced Coastal bermudagrass winter injury and indicated that winter survival of this grass was favored by a high ratio of applied K to N. Kiesling et al. (1979) reported that K fertilizer dramatically increased visual stand ratings on Darco and Cuthbert soils, and that rhizome production was increased by added K. Nelson et al. (1983) indicated that K application had no significant effect on Coastal bermudagrass yield on a Darco soil, but increased 3-yr. average yields on a Cuthbert soil. Soil test K levels of both Coastal Plain soils declined at each rate of applied K, suggesting that 300 lb K_2O/A was inadequate for K fertility maintenance in Coastal bermudagrass production. Adams et al. (1967) reported no significant difference between KCl and potassium sulfate (K_2SO_4) with respect to forage yields or K content at the 200 lb or 800 lb K_2O/A rate. Miller and Dickens (1996) studied KCl vs K_2SO_4 applied twice monthly with N and reported high K rates did not increase bermudagrass rhizome cold resistance, and therefore may be of no benefit beyond K rates sufficient for optimum yield. Numerous papers reported response of Coastal bermudagrass to K applied as KCl, but none have evaluated the effect of Cl applied as KCl.

Objectives of this study were to determine the main and interactive effects of K, Cl, and S on Tifton 85 bermudagrass yield, stand decline, and disease suppression at moderate and high N rates. Additionally, treatment effects on soil and plant nutrient content were determined.

After harvesting, forage from plots was weighed and sampled for DM and chemical analysis.

Tifton 85 bermudagrass has improved nutritive value and yield potential, but more information on effects of nutrients is needed.

Darco loamy fine sand (Grossarenic Paleudult; a deep sandy soil), earlier treated with 3 tons/A ECCE 100% limestone was treated with an additional 2 tons/A ECCE 72% limestone and fertilized with 180 lb P_2O_5/A in April 2001. Treatments were incorporated by disking about 6-in. deep. Tifton 85 was sprigged on April 24, 2001, and the site was irrigated with 0.5 in. of water after applying 68 lb N/A as ammonium nitrate.

Main-plot N rates of 60 and 120 lb N/A for each regrowth of bermudagrass were strip-applied as replications. Split-plot K sources were KCl, K_2SO_4, and KCl+S at 134, 268, and 402 lb K_2O/A. The K rates were split applied after the first season, one-third prior to regrowth in spring and one-third after each of two cuttings. Rates of Cl and S applied with the various K treatments are shown in **Table 1**. The N rates were increased to 80 and 160 lb N/A for each bermudagrass regrowth in 2004. Phosphorus was reapplied at 120 lb P_2O_5/A each spring. Harvests were made with a Swift Machine forage plot harvester (**see photo**). Forage from each plot was weighed and sampled for DM and chemical analysis. Soil samples for chemical analysis were collected after the 2003 growing season.

Abbreviations and notes for this article: K = potassium; S = sulfur; N= nitrogen; Cl = chloride; KCl = muriate of potash or potassium chloride; DM = dry matter; ECCE = effective calcium carbonate equivalence; ppm = parts per million.

Table 1. Rates of Cl and S applied with K fertilizer treatments.

K rate, lb K_2O/A	Source KCl Cl rate	 K_2SO_4 S rate	 KCl+S Cl rate	 S rate
	- - - - - -	- - - - - -	lb/A - - - - - -	- - - - - -
134	107	46	107	46
268	214	91	214	91
402	322	137	322	137

Table 2. Tifton 85 bermudagrass dry matter yield response to K, Cl, and S at two N rates.

Treatments	Dry matter yield by year 2001	 2002	 2003	 2004
	- - - - - -	- - - - - - lb/A	- - - - - -	- - - - - -
N[1], lb/A				
60	3,779 ns	10,258 ns	12,562 ns	11,693 b[2]
120	3,359	11,562	13,703	13,856 a
K[3], lb K_2O/A				
0	3,300 ns	9,118 b	10,831 b	9,614 c
134	3,636	11,111 a	12,983 a	12,469 b
268	3,870	11,156 a	13,338 a	13,246 a
402	3,290	11,060 a	13,844 a	13,662 a
K source				
KCl	4,126 ns	11,230 ns	13,097 ns	12,002 c
K_2SO_4	3,347	10,754	13,498	13,301 b
KCl + S	3,324	11,343	13,570	14,074 a
Coeff. of var.	49.2	17.7	7.8	8.5

[1] N rates applied at green up and after each cutting. N rates increased to 80 and 160 lb/A in 2004.

[2] Yields within a column and group followed by a dissimilar letter are significantly different (p = 0.05).

[3] Rates of K split-applied at initiation of regrowth and twice during the growing season in 2002, 2003, and 2004. In 2001, K rate was applied one-half at growth initiation and one-half on September 28.

Deficiency of S was visually evident in the first year of study, but DM yield was not affected until year 4.

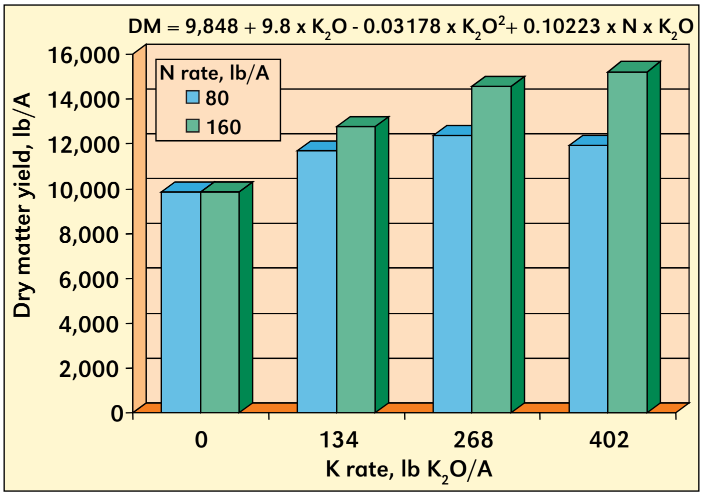

Figure 1. Effect of increased N rate on Tifton-85 bermudagrass response to K in 2004. Nitrogen rates applied for each of five cuttings. Rates of K applied at initiation of regrowth and twice during growing season.

The high coefficient of variation (cv) for the single harvest in 2001 indicates that Tifton 85 stand density was not uniform, but did improve with establishment in the ensuing years (**Table 2**). A statistically significant increase in total DM occurred at 134 lb K_2O/A in 2002 and in 2003. Source of K had no significant effect on DM production the first 3 years. In 2004, K source increased DM yield in the order KCl+S > K_2SO_4 > KCl, indicating that S and Cl had declined to deficient levels. In the first season, S deficiency was visually evident in bermudagrass that received no S, but DM yield was not affected by S deficiency until year 4 (**see photo**). In year 4, increasing the K rate to 268 lb K_2O/A increased total DM yield compared to the 134 lb K_2O rate, suggesting that soil K was being mined at the lower rate. Declining K levels were detected in soils. A significant interaction between N and K showed that greater rates of K are required to obtain the higher

Table 3. Tifton 85 bermudagrass K, Cl, S, and N concentrations and uptake, 2004 data.

Treatments	K Conc., %	 Uptake, lb/A	Cl Conc., %	 Uptake, lb/A	S Conc., %	 Uptake, lb/A	N Conc., %	 Uptake, lb/A
N[1], lb/A								
80	2.22 ns	258 b[2]	0.19 a	23	0.29 a	34	2.23 b	249 b
160	2.15	301 a	0.15 b	21	0.27 b	38	2.84 a	383 a
K[3], lb K_2O/A								
0	1.26 d	114 d	0.09 c	8 d	0.18 d	16 d	2.80 a	268 c
134	1.81 c	219 c	0.16 b	20 c	0.24 c	29 c	2.53 b	308 b
268	2.38 b	309 b	0.18 a	24 b	0.29 b	38 b	2.49 b	325 ab
402	2.67 a	365 a	0.19 a	27 a	0.34 a	48 a	2.49 b	332 a
K source								
KCl	2.30 ns	273 c	0.24 a	30 b	0.18 c	19 c	2.62 a	310 b
K_2SO_4	2.20	297 b	0.07 c	8 c	0.37 a	50 a	2.45 b	322 ab
KCl + S	2.33	323 a	0.22 b	33 a	0.33 b	46 b	2.44 b	333 a

[1] N rates applied at green up and after each cutting.

[2] Yields within a column and group followed by a dissimilar letter are significantly different (p = 0.05).

[3] Rates of K split applied at initiation of regrowth and twice during the growing season.

yields expected at higher N rates when water is sufficient for increased yields (**Figure 1**).

Table 4. Extractable plant nutrient levels and pH in 0 to 6-in. depth of Darco soil after the 2003 growing season[1].

	Soil pH and nutrient levels after 4 years of treatments						
	pH[1]	K	SO_4-S	Cl	P	Ca	Mg
Treatments				ppm			
N[2], lb/A							
60	6.8 a[3]	34 a	12 ns	4 ns	84 ns	976 ns	40 ns
120	6.2 b	22 b	14	4	77	717	38
K[4], K_2O, lb/A							
0	6.4 ns	17 c	11 b	4 ns	89 ns	768 ns	34 ns
134	6.5	19 c	11 b	3	83	842	40
268	6.6	30 b	12 b	4	77	891	40
402	6.5	39 a	17 a	5	80	833	39
K source							
KCl	6.6 a	33 a	11 b	4 a	77 ns	871 ns	39 ns
K_2SO_4	6.7 a	30 a	12 b	2 b	81	882	40
KCl + S	6.3 b	24 b	17 a	5 a	81	813	

[1] pH in 1:2 soil: water; P by ammonium acetate-EDTA (Hons et al.) extraction and colorimetric analysis; K, Ca, and Mg by ammonium acetate-EDTA extraction and atomic absorption analysis; S by extraction with ammonium acetate-acetic acid and turbidometric analysis; and Cl by extraction with 0.01 M $Ca(NO_3)_2 \cdot H_2O$ using thiocyanate-ferric nitrate color development.

[2] N rates applied at green up and after each cutting.

[3] Yields within a column and group followed by a dissimilar letter are significantly different ($p = 0.05$).

[4] Rates of K split applied at initiation of regrowth and twice during the growing season.

Increasing the K rate increased plant K concentration (**Table 3**). At low application rates, KCl increased plant K compared to K_2SO_4 and KCl+S, and at the high application rate, plant K was highest (2.8%) with application of KCl+S and was lowest (2.6%) in plants treated with KCl (data not shown). However, when averaged over N and K rates there was no K-source difference in plant K levels. Higher DM yields increased K uptake by the bermudagrass. Plant Cl concentration was highest in the order KCl > KCl+S > K_2SO_4 and declined with increasing N rate. As the K rate was raised to 402 lb K_2O/A, Cl levels in plants increased to 0.19%. However, at similar K rate increases applied as K_2SO_4, plant Cl concentration declined from 0.09 to 0.06% (data not shown). Plant Cl content and uptake increased with higher K rates. Plant S levels from all K sources declined with increasing N rates, and were elevated from 0.18 to 0.34% with increasing rates of K_2O. However, plant S remained constant at 0.18% as the rate of K as KCl was raised (data not shown). Plant N concentration was increased by the higher N rate and declined as yield was increased with applied K. The seasonal average main effect N:S ratio declined from 17.3 to 9.4 as the K rate was increased from zero to 402 lb K_2O/A and increased from 9.3 to 13.2 as the N rate was raised from 80 to 160 lb/A. Seasonal average main effect N:S ratios by K source were 16.3 for KCl, 7.5 for K_2SO_4, and 8.1 for KCl+S.

In general, increasing K rates from zero to 402 lb K_2O/A significantly increased soil K in the 0 to 6-in. depth (**Table 4**) and at depths to 24-in. after 3 years of treatment (data for depths below 6-in. not shown). However, regardless of this increase, all surface-depth K levels remained in the very low soil test rating category. At depths deeper than 24-in., higher K rates were needed to increase extractable soil K. Higher yields at constant rates of K_2O decreased surface depth levels of plant-available soil K. Extractable S levels were increased where KCl+S was applied and at the highest K rate. Soil Cl levels declined to 2 ppm when Cl was not included in the K treatment. Soil pH significantly declined at the high N rate and with the KCl+S treatments. Extractable levels of P, Ca, and Mg were unaffected by treatment. At the zero K rate, bermudagrass stand decline was visually detected in the initial spring regrowth, but only a minor incidence of the disease *Helminthosporium* leaf spot was observed in one season. The low level of disease incidence could not be correlated with a particular treatment.

Conclusion

Tifton 85 bermudagrass DM yields were increased by K sources in the order KCl+S > K_2SO_4 > KCl. The main effect DM yields were significantly increased at 268 lb K_2O/A. The yield curve peaked near 268 lb K_2O/A at the 80 lb N/A treatment, while DM yield continued to increase at 402 lb K_2O/A when the N rate was increased to 160 lb N/A for each cutting of grass. Regardless of the significant increases in soil K level with addition of K, these soil K levels were all in the very low category and the bermudagrass depended on applied K for adequate growth. In addition to applied K and N, S and Cl were needed for increased yields of bermudagrass.

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CHINA

Potassium Balance on Sloping Lands as Affected by Farming Systems

By Qing Zhu, Shihua Tu, Zhenggang Chen, and Zhaoqian Wang

This study assessed the available soil K balance under five different farming systems in southern Guizhou from 2000 to 2004. The negative impacts of traditional down slope cultivation were quantified relative to improved systems. Cash crop hedgerows can be highly effective in controlling soil erosion and preserving soil K.

The susceptibility of K to leaching and the impact of K losses on degrading soil fertility and productivity has been well documented (Adisak et al., 2002; Fardeau et al., 1992; Johnston and Goulding, 1992; Kaddar et al., 1984; Nativ, 1992). On sloping lands, loss of K through soil erosion and runoff may be more serious. Besides rainfall and landscape type, improper tillage, incorrect fertilization, and cropping patterns are known to induce soil K loss by encouraging soil erosion. Recent use of integrated cash crop hedgerows has been proven successful in combating soil erosion in southwest China, but a detailed study on soil K balances is lacking. The objectives of this project were to study the differences in K dynamics as affected by farming systems, and to evaluate soil K balance under five different farming systems in southern Guizhou.

Researchers selected a 30 ha agricultural watershed located at Xinlong Township, Luodian County, Guizhou Province (E106°46', N25°26') with 6 ha of paddy rice and 24 ha of upland crops and fruits. Slopes vary between 11 to 24°. Soils are classified as red-yellow (Hapludalf), developed from Devonian and Cretaceous carbonaceous shale, dominated with quartzes, kaolin, and hydrous micas. The area lies in subtropical, monsoon climate zone with annual precipitation of 1,200 mm. Though rains are usually concentrated from April to September, drought spells often appear in summer and autumn. Corn, the local staple food crop, is widely grown on these slopes using a traditional, erosion-prone, down slope cultivation method.

The experiment used a randomized complete block design with five treatments and four replications (**Table 1**). All the treatments were grown across the slope except traditional farmers' practice (FP), which was grown down the slope. Two types of hedgerows were introduced, buckwheat + plum (AC1) and daylily (AC2). They were grown across the field with 5 m spacing between hedge belts (**see photo above**). The engineered terrace (ET) treatment copied the commonly used practice of reshaping fields into plots 6 m wide and 3 m in length, with 2° slope. All other treatments shared an initial slope of 17° and a plot area of 11 m × 6 m separated by a cement plate. Water tanks were built to receive runoff and sediment at the bottom of each plot.

Table 1. Amount of runoff and available K lost as affected by different treatments.

Treatment	Runoff, t/ha	Reduction vs. FP, %	Available K in runoff, kg/ha
Buckwheat + plum (AC1)	1,996 a	43.3	16.0
Daylily (AC2)	2,130 a	39.5	14.8
Engineered terrace (ET)	2,315 ab	34.2	19.2
Balanced fertilization (BF)	2,756 b	21.7	19.7
Farmer's practice (FP)	3,519 c	-	23.1

Different letters mean significant at 0.05 levels, respectively

Two types of hedgerows, buckwheat + plum and daylily, were grown across the field with 5 m spacing between hedge belts.

Soil samples taken prior to the experiment determined basic soil physiochemical properties. The soil was acidic with a pH of 5.7 and the mechanical composition was 70.5% clay, 10.6% silt, and 18.8% sand. Soil samples were taken before seeding and after harvesting to analyze available K and slowly-available K using the methods as described by Knudsen et al., 1982.

Fertilizers included 270 kg N/ha as urea (N = 46%), 105 kg P_2O_5/ha as single superphosphate (P_2O_5 = 16%), and 18 t farmyard manure/ha (N = 0.5%, P_2O_5 = 0.25%, K_2O = 0.6% on a wet weight basis) for the FP treatment. The other treatments received 270 kg N/ha, 105 kg P_2O_5 /ha, 105 kg K_2O/ha as KCl (K_2O = 60%), 6 kg Zn/ha as zinc sulfate (Zn = 23%), 1,950 kg burned lime/ha (CaO = 70%), and 18 t farmyard manure/ha. Except N, all the other fertilizers were applied as basal fertilizers prior to seeding corn. Nitrogen was split twice between corn seedling and earring stages.

Corn biomass and seeds, daylily flowers, and buckwheat were collected from each plot to determine yield and nutrient uptake. Rainfall data was recorded using a local meteorological station. Soil loss and runoff from the plots were collected and measured manually after each rain event. Soil loss was estimated from sediment samples taken from the final sus-

Abbreviations and notes for this article: K = potassium; N = nitrogen; P = phosphorus; KCl = potassium chloride.

Table 2. Potassium balance in topsoil before planting and after harvesting.

	K in top soil before planting, kg/ha			K in top soil after harvesting, kg/ha			Balance, kg/ha	
Treatment	Total	S.A. K[1]	Avail. K[2]	Total	S.A. K	Avail. K	S.A. K	Avail. K
AC1	49,974	659.4	155.5	49,755	353	208	-306	52
AC2	46,351	572.2	179.0	45,253	294	202	-288	23
ET	46,542	604.0	179.6	48,971	349	203	-255	24
FP	40,300	576.4	153.8	39,167	401	126	-175	-28
BF	45,469	651.3	154.8	47,219	369	153	-282	-2

S.A. K[1] = slowly available K; Avail. K[2] = available K.

Table 3. Available K balance on sloping land.

	Additions, kg/ha			Removals, kg/ha						
Treatment	Rain	Fertilizer	Subtotal	Corn grain	Corn stalk	Hedge crop	Runoff	Sediment	Subtotal	Balance, kg/ha
AC1	3.5	176.8	180.3	12.1	42.8	32.7	14.8	4.5	106.9	73.4
AC2	3.5	176.8	180.3	10.9	47.5	31.7	16.0	5.9	112.1	68.2
ET	3.5	176.8	180.3	10.4	31.4	-	19.2	5.0	66.0	114.3
FP	3.5	89.7	93.1	9.6	18.8	-	23.4	9.4	61.3	31.9
BF	3.5	176.8	180.3	12.2	56.7	-	19.7	6.4	94.9	85.4

pension of sediment collectors (Rowell, 1994). Soil and plant analyses were conducted in the Guizhou Soil and Fertilizer Institute, Guizhou Academy of Agricultural Sciences.

Results suggest that the best measure to conserve soil K is to control water losses. Hedgerow treatments were highly effective in controlling runoff compared to the BF and FP treatments (**Table 1**). No difference in runoff losses was observed between ET and BF or hedgerow treatments. Available K lost to runoff varied among treatments with the hedgerow treatments being lowest and farmers' practice highest.

Differences in slowly-available K between pre-planting and post-harvest were negative for all treatments (**Table 2**). Slowly-available K was reduced the most under AC1 > BF > AC2 > ET > FP. Available K decreased with FP, remained fairly constant under BF, and increased under the two hedgerow treatments and ET. A sum of the balances for slowly-available and available K after harvest resulted in the following order of K deficit: BF > AC2 > AC1 > ET > FP. While the order might appear surprising at first glance, if one considers evidence which follows on corn yield and hedgerow crop harvest, it is obvious that the reduction in soil K during the cropping season is most correlated to crop yield, or alternatively, K removal by corn. The high reduction in slowly-available K in the BF and hedgerow treatments is most likely a result of high available K demand by the corn and hedge crops. This demand necessitated a more rapid conversion of slowly-available K to available K.

The comparison of K additions and removals, as influenced by treatment, are provided in **Table 3**. All treatments contributed to positive balances. The highest K surplus occurred under ET and the lowest occurred under FP. The FP treatment supplied the lowest fertilizer K–only half the amount used in the other treatments–and was most susceptible to soil erosion and water loss. Farmers' practice had the lowest crop K removal, but this could not be offset by its low K input. The highly positive K balance under ET was a result of much lower crop K removal (i.e., low corn K removal and no hedgerow K removal) despite receiving the same fertilizer K input as the two hedgerow treatments.

Crop uptake was responsible for the majority (46 to 82%) of soil K removal – 31 to 60% remaining in corn stalks, 28 to 31% removed by hedge crops, and 10 to 16% translocated to harvested seed/grain. In all treatments, the majority of soil K removal was a result of growing corn (grain + stalk) which accounted for 46 to 72% of total K removal. Runoff was the main pathway for permanent available soil K loss, accounting for 14 to 38%, while soil erosion accounted for only 5 to 15%.

The FP led to the highest non-crop related K loss from sloping lands – losses to soil erosion and runoff accounted for 53% of total removal, or 35% of the total K input. In the two hedgerow treatments, K lost to soil erosion and runoff was limited to about 20% of total K removal and the remaining 80% was taken up by the corn and hedge crops – a remarkable demonstration of the effect of these hedgerows on minimizing soil nutrient losses.

Traditional farmers' practice was very susceptible to soil erosion and water losses. All treatments showed large reductions in slowly-available soil K due to crop removal. Available soil K increased within the two alternative hedgerow cropping systems and engineered terracing. Integrated practices which make proper use of K fertilizer, crop residue recycling, and soil conservation technology are key components to managing the region's soil K balance.

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Influence of Starter Fertilizer on Corn Yield and Plant Development on Mississippi River Alluvial Soils

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Application of in-furrow N-P fertilizers on sandy loam and silt loam soils in Louisiana increased corn yield in 5 of 15 trials. Starter fertilizer consistently increased early-season plant growth, advanced silking date, and decreased harvest grain moisture.

Mid-March to early April planting dates required for optimal corn production in Louisiana often result in exposure of seedlings to lower than optimal soil temperatures. Low soil temperatures may result in slow plant growth and temporary P deficiency, even though levels of extractable soil P may be considered adequate for plant growth.

Phosphorus deficiency symptoms on corn seedlings are commonly seen and are most pronounced on sandy loam and silt loam Mississippi River alluvial soils with organic matter content less than 1%. Often, soil temperature at the 2 in. depth in early March on the productive Commerce silt loam soils (thermic Fluvaquentic Endoaquepts) may be as much as 5 °F lower than on clayey soils (e.g. Sharkey clay – thermic Chromic Epiaquerts).

Symptoms of P deficiency common on sandy and silt loam soils rarely occur on the finer-textured silty clay and clay soils. Placing small amounts of starter fertilizer in close proximity to the seed at planting could alleviate the effects of cold soil temperature on P uptake and early corn growth. A 2x2 placement (2 in. below and to the side of seed) has been thoroughly evaluated, and some research has been conducted on placement of the starter directly with the seed. Direct placement is practical and economic in a corn-cotton production system, since cotton producers typically use in-furrow equipment for insecticide and/or fungicide applications. Excessively high starter fertilizer rates applied in-furrow can injure plants.

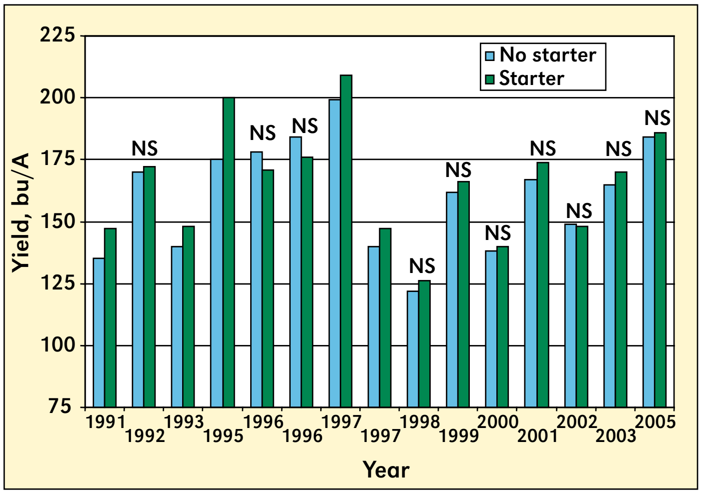

Figure 1. Influence of starter fertilizer on corn yield on Mississippi River alluvial sandy loam/silt soils at the Northeast Research Station at St. Joseph, Louisiana.
NS= Non-significant at the 0.05 probability level.

In-furrow N-P starter fertilizers offer several advantages for corn on sandy loam and silt loam soils in Louisiana.

Fifteen trials were conducted between 1991 and 2005 at the Northeast Research Station near St. Joseph, Louisiana, to evaluate the effectiveness of in-furrow starter fertilizers. Some of these experiments included variables other than starter fertilizer. However, for this summary, only the main effects of starter fertilizer are reported.

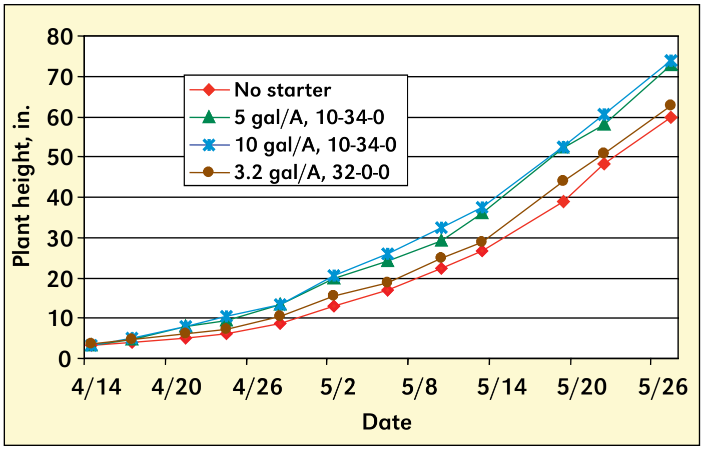

Figure 2. Influence of in-furrow starter fertilizer treatments on plant height during the growing season on Commerce silt loam at St. Joseph, 2003.

Abbreviations and notes for this article: N = nitrogen; P = phosphorus.

Corn was planted following cotton from early March to early April at about 28,000 seed/A. Ammonium polyphosphate (11-37-0 or 10-34-0) was applied at 2.5 to 10 gal/A. In most trials, the recommended rate of 4 to 5 gal/A was compared to a no-starter control. Grain yield, silking date, and harvest grain moisture were determined, and plant development was monitored during the growing season (plant dry weight and/or plant height). Extractable soil P levels in the test area were considered high each year, according to analyses conducted by the LSU Agricultural Center Soil Testing Laboratory.

Average corn grain yields ranged from 124 to 204 bu/A. The in-furrow N-P starter fertilizer application significantly increased yield in 5 of the 15 trials and responses in these trials ranged from 8 to 25 bu/A, with an average starter response of 12.5 bu/A (**Figure 1**). No grain yield response to starter occurred in 9 of the 13 years evaluated. Phosphorus deficiency symptoms and starter responses were most common on the more coarse-textured soils. The largest yield response (25 bu/A) occurred on a sandy loam soil. These sandy, low organic matter, light colored soils are cold-natured. Plants on these soils are more susceptible to reduced early season P availability than on finer-textured soils. This probably accounts, to a large extent, for the low incidence of early season P deficiency symptoms and smaller yield responses to starter on clayey soils.

Although starter fertilizer increased yield in only one third of the trials, early season plant growth was increased in all trials. A typical plant growth response to starter is shown in **Figure 2**. Two rates of starter increased plant height from the early seedling to tassel growth stages, while starter N alone had little affect on plant growth. This confirmed that growth responses on sandy loam and silt soils are primarily due to the P in the starter, probably because of reduced P availability on the cold-natured soils.

Table 1. Influence of starter fertilizer on average mid-silk date and harvest grain moisture in 15 trials on Commerce silt loam at the Northeast Research Station at St. Joseph, 1991 through 2005.

Starter yield response	Number of trials	Mid-silk date No starter	 Starter	Harvest grain moisture, % No starter	 Starter
		------ DAP[1] ------			
Yes	5	73	69	17.1	16.1
No	10	72	69	18.7	18.2

[1] DAP = days after planting

Enhanced plant growth with starter hastened maturity, which was reflected in advanced mid-silk dates and lower harvest grain moistures. Starter fertilizer reduced mid-silk dates by 4 days when yield responses occurred and by 3 days when no yield response occurred (**Table 1**). Harvest grain moisture was 1% lower in trials with starter yield responses and 0.5% lower in trials with no yield response to starter. This could result in earlier harvest and lower drying costs, which may lead to higher net profit.

Early rapid plant growth also hastens canopy closure, reducing weed development and the need for herbicides.

Planting from mid-March to early April and using starter fertilizer would help ensure consistent maximum corn yield production and minimal conflict with cotton production practices in both spring and fall. Since starter fertilizer such as ammonium polyphosphate can be applied with the same in-furrow application equipment currently used to apply fungicide and insecticides at planting, the only additional cost is the fertilizer expense. At current starter fertilizer prices of $1.65/gal, the application of 4 to 5 gal/A is relatively inexpensive insurance, especially on cold-natured, coarse-textured soils. BC

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Potassium Balance...from page 7

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Spatial Variability in Available Nutrient Status in an Intensively Cultivated Village

By P. Sen, K. Majumdar, and Gavin Sulewski

Available nutrient status showed wide variation across the study area which was associated with fertilization history and the cropping sequence adopted by individual farmers.

Fertilizer management is a major consideration in agricultural production. Inadequate fertilizer application limits crop yield, results in nutrient mining, and causes depletion of soil fertility. An excessive or imbalanced application not only wastes a limited resource, but also pollutes the environment. So farmers are faced with an ever-increasing demand for finely tuned fertilizer management – with economic optimization on one hand and environmental concerns on the other. An approach towards mitigating such concerns is site-specific nutrient management (SSNM)...as opposed to a blanket fertilizer recommendation followed over an extended area irrespective of soil and crop concerned...which takes into account spatial variations in nutrient status cutting down the possibility of over or under use of fertilizer. The current study evaluates the extent of spatial variations in available nutrient status at Sripurdanga Village of Murshidabad District in the alluvial soil zone of West Bengal, India, to highlight the need of factoring in such variations in fertilizer management.

The soil in the study area is a fine loamy Typic Ustifluvent. Rice is the major crop in this area, grown twice a year during February to May and July to October. A variety of other crops, including vegetables, pulses, oilseeds, jute, and flowers make up the cropping sequences. Average farm size is 1 ha or less and fertilizer applications are limited to farmers' perception, or at best, based on general recommendations provided for the whole state. Average rainfall is 1,340 mm and average temperature varies between 8 to 40 ºC.

A total of 32 soil samples were collected from 0 to 15 cm depth at a 100 x 100 m grid during April 2006. GPS coordinates of the sampling points were recorded using a GARMIN Map 60 instrument. Soil physiochemical properties and available nutrient status were measured by standard procedures (Page et al., 1982). Descriptive statistics of the measured soil properties showed wide variations (**Table 1**). Except for pH, all the other parameters had CV values greater than 24%, the highest being 90% in the case of Fe.

A survey of the cropping systems and fertilization history for the study area was performed to relate nutrient variability with existing farming practices. High spatial variability in soil P content was found to be a result of differences in P application rates between vegetable farmers and rice farmers. Variability in soil S content could be related to S application by some farmers, through single superphosphate, and a lack of such application by other individuals. Potassium has lower spatial variability compared to P and S, most likely due to generally low application rates (Wang et al., 2006). Thus, the main source of variability for soil K was related to type of crop cultivated rather than application rates. The high variability for all micronutrients, except Cu, was quite surprising and needs further study for a proper explanation (**Table 1**).

Various studies have shown that spatial variability of soil properties, including nutrient status, can occur across fields owing to tillage, fertilization, cropping history, and other reasons. A study on soil fertility variability within a 50 ha cotton field in Handan County of Hebei Province, China, showed remarkable variability in available soil nutrient content with available P, K, and B having CVs greater than 30% after 20 years of small-scale operations. A similar study on a 20 ha field within a large-scale, single operational unit (Changyang State Farm) in the suburb of Beijing showed a lower extent of spatial variability compared to small-scale operations (Jin, 2005). Under the small-scale operations, where each farming family operated small plots, the variability of soil nutrients had a close relation with history of fertilization, crop variety, and field management.

Spatial variability maps of the soil nutrient status, soil pH, and organic C were created for the study area using GIS (ESRI, 2001) by overlaying the soil nutrient contour maps over the sample point distribution map (**Figure 1**). The P distribution map shows high available P in most parts of the study area except for some isolated patches of medium P fertility. This was most likely due to high P input in all crops in this area, mostly through diammonium phosphate (DAP) application. Higher available soil P content was found in part of the study area where vegetables are grown with much higher P inputs compared to other crops.

However, K fertility status was found to be rather low in the study area. Except for some isolated patches of high K content, most of the soils have very low to medium fertility. As with P, a distinct region of the southern part of the study area had higher

Table 1. Descriptive statistics of the measured soil properties at the experimental site.

Property	Minimum	Maximum	Mean	Standard deviation	CV, %
pH	6.8	7.9	7.4	0.3	4
EC, ds/m	0.1	0.7	0.4	0.2	58
Organic C, %	0.2	1.1	0.7	0.2	25
Total N, %	0.02	0.09	0.06	0.01	24
P_2O_5, kg/ha	50.4	366.4	194.0	98.7	51
K_2O, kg/ha	87.0	448.0	254.2	93.0	37
S, ppm	7.8	82.5	19.5	12.8	66
Zn, ppm	0.2	3.8	0.9	0.7	73
B, ppm	0.4	5.0	2.0	1.2	57
Fe, ppm	1.8	40.	7.8	7.0	90
Cu, ppm	1.1	3.5	2.0	0.5	24
Mn, ppm	2.6	35.8	12.0	8.9	74

Abbreviations and notes for this article: GPS = global positioning system; GIS = geographic information systems; CV = coefficient of variation; N = nitrogen; P = phosphorus; K = potassium, Fe = iron; S = sulfur; Mn = manganese; B = boron; Zn = zinc; C = carbon; ppm = parts per million.

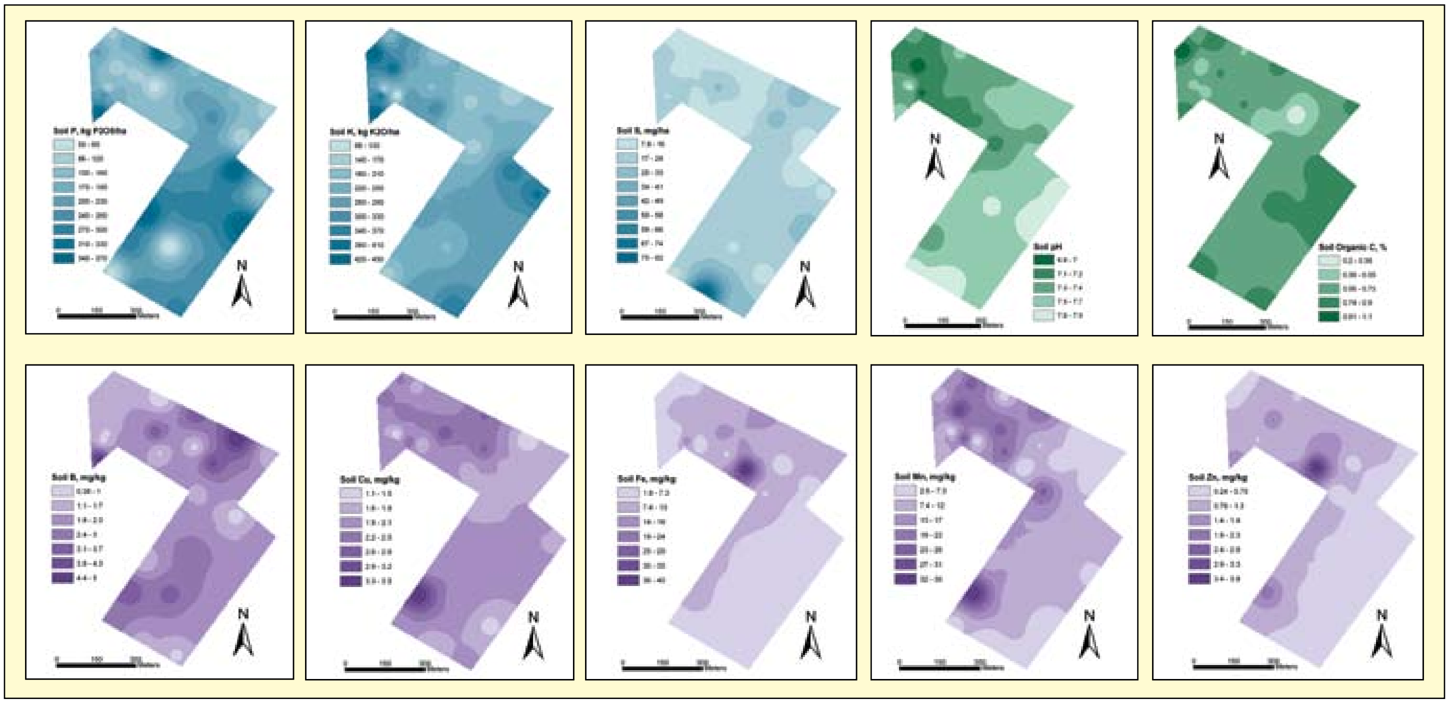

Figure 1. Distribution of available P, K, S, B, Cu, Fe, Mn, Zn, soil pH, and organic carbon at the experimental site near Sripurdanga Village, West Bengal, India.

K content compared to other areas. Our survey revealed that farmers grow vegetables in this area and consequently apply more nutrients than in cereals.

The average application rate for K fertilizers is much less than N and P fertilizers. Low use of K fertilizers and high leaching loss of K due to frequent irrigation are the most likely reasons for widespread K deficiency in the village, irrespective of cropping systems followed.

The survey revealed that multi-nutrient deficiencies have developed in fields where farmers opted to follow a particular cropping system for several years. Deficiencies of K, Zn, and Fe have developed in fields where jute/paddy/wheat or jute/paddy/paddy sequences were followed for the last 7 to 10 years. The sandy loam to loam texture of the soil and prevailing soil pH above 7.0 are main contributing factors to this region's Zn and Fe deficiencies. Besides, lack of organic matter application coupled with no application of Zn in a rice-based system will aggravate soil Zn deficiency.

In general, the study area was found to be deficient in available S. Sulfur deficiency was particularly widespread in fields where one or two oilseed crops are included in the cropping sequence. More often than not, farmers use high analysis fertilizers with little or no S and irrigate their fields frequently. In absence of adequate S, cultivation of one or two oilseed crops…or vegetables of the cruciferous family such as cabbage and cauliflower…can cause acute S deficiency in the soil. The survey and soil analysis reports also showed that S deficiency of soils can be avoided with application of S fertilizer at least once in a cropping sequence.

Spatial variability for micronutrients can be partially explained with in-situ knowledge of the study area's production systems. Relatively high concentrations of Cu can be related to the frequent use of pesticides containing Cu. The maps for Zn and Fe show deficient areas in the southeast and northwest. Both of these areas have extended rice/vegetable sequences and the resulting nutrient removal would be high. Rice demand for Zn and Fe is high and removal would be further accelerated under the higher nutrient input situation of growing vegetables.

The northwestern part of the study area also represents a significant area of B deficiency. The northwest represents a transition zone between the uplands and lowlands and continuously higher soil moisture contents would contribute to higher leaching of B from this area.

The current study revealed major variability in soil nutrient status within a small area of an intensively cultivated village. The cropping pattern and fertilization history of individual plots seemed to be the cause of such variability.

The fertilization plan of an individual farmer should take into account this variability to optimize nutrient application rates for better yield and economics of crop production. Experiments are now being designed to develop SSNM strategies for the area based on spatial nutrient variability maps. BC

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Potential Biofuels Influence on Nutrient Use and Removal in the U.S.

By Paul E. Fixen

Nutrient use and management will likely be impacted significantly within the next 5 years through grain-based ethanol production. Beyond that time period, another round of major impact may occur as cellulosic biofuel production is commercialized. A major challenge to the fertilizer industry and those conducting research on nutrient management will be the development of nutrient management approaches focused on ecological crop intensification where productivity is increased to meet growing demand and the environment is improved. Failing to take this challenge seriously will likely lead one day to headlines in the media about the "misadventure" of biofuels and the loss of a tremendous opportunity for agriculture.

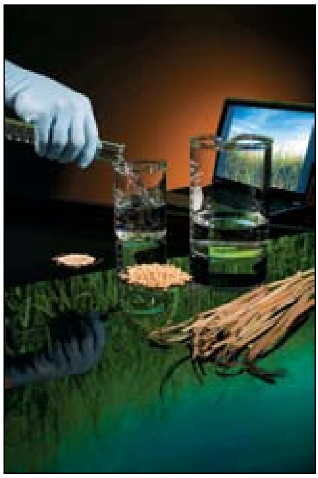

Photo: USDA-ARS, Peggy Greb

"*Upon this handful of soil our survival depends. Husband it and it will grow our food, our fuel, and our shelter and surround us with beauty. Abuse it and the soil will collapse and die, taking man with it.*" This quote is attributed to the Sanskrit literature from around 1500 BC (Johnston and Dawson, 2005). It is a clear reminder that agriculture as a source of fuel is far from a new concept. However, the advent of new technology…coupled with a desire to reduce dependence on imported oil…has us in the midst of a modern day agricultural revolution. This ancient quote also reminds us of the importance of resource stewardship as agriculture strives to capitalize on the opportunities biofuels provide.

Intensified Interest in Yield Improvement

The increased demand for corn can be met by either increasing acres or increasing production per acre. Higher crop prices offer incentive for both. This production-encouraging market comes at a time when biotechnology and genetics industries are promising leaps in genetic yield potential with estimates of 3% per year being made by leading biotechnology companies (Fitzgerald, 2006). **Figure 1** shows what a 3% annual rate of increase looks like projected out to 2020 and contains a table translating the yield increases into additional production relative to 2006. The N, P, and K contained in the additional annual production in 2020 amounts to 18, 21, and 13%, respectively, of the entire current U.S. fertilizer use (average of 2004-2006). If the genetics industry can deliver on the promised increased genetic potential, and if agronomic researchers, educators, crop advisers, and growers can convert that genetic potential into bushels in the bin, we will indeed be in the midst of a revolution not experienced since the hybridization of corn.

Converting genetic potential into harvestable yield should clearly not be taken for granted. Cropping system changes in plant population, fertilization, pest management, tillage, and other cultural practices will likely be necessary on a site-specific basis. The yield drag of increased corn-on-corn acres will need to be overcome. And, it will be critical for sustainability of the resulting modified system that the changes contribute positively to environmental impacts…that nitrate and phosphate losses to surface water and groundwater are reduced, soil erosion and soil loss from the field are lessened, nitrous oxide and ammonia emissions to the atmosphere are reduced, carbon is sequestered in the soil or at least maintained, and water is used appropriately.

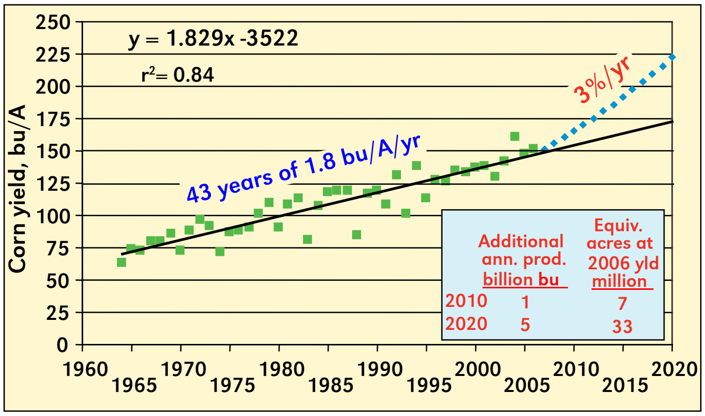

Figure 1. Genetic improvement in corn yields promised by the biotech industry.

Increase in Corn Acreage

A substantial increase in corn acreage is predicted in 2007 and about a 10 to 15% increase over the 2004-2006 average acreage (80.3 million) is anticipated over the next couple years by many. Much of the increase is likely to occur in the traditional corn-soybean rotation region of the Corn Belt, resulting in an increase in corn-on-corn acres. **Table 1** gives an estimate of the impact of a 5 million acre shift of soybeans to corn where use per acre on the new corn area is assumed to be the same as reported in the USDA Ag Chemical Use Survey for the 2 most recent survey years, plus an additional 30 lb N/A to compensate for loss of a soybean previous crop credit.

Table 1. Impact of adding 5 million acres of corn from soybean acreage in the U.S.

	Fertilizer use, 1,000 tons		
Change	N	P_2O_5	K_2O
+5 million acres of corn	405	117	135
-5 million acres of soy	-13	-38	-68
+5 million acres with N adjustment for cont. corn	75	0	0
Net	+467	+79	+68
U.S. fertilizer use (04-06)	12,320	4,570	5,110
% increase	3.8	1.7	1.3

Based on USDA Ag Chemical Use Survey; average of 2003 and 2005 for corn plus 30 lb/A for continuous corn; 2002 and 2004 for soybeans.

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

The fertilizer that would have been applied for soybeans is subtracted from the corn fertilizer. The estimation also accounts for the increased N rate needed for the additional corn-on-corn acres that show up in the second year of the increased corn acreage. Since there are 5 million fewer acres of soybeans to rotate with corn, an increase of 5 million acres of corn results in 10 million acres of corn-on-corn. With these assumptions, a 5 million acre increase in corn results in increases of 3.8, 1.7, and 1.3% in U.S. total fertilizer use over the 2004-2006 average. If 10 million acres shift from soybeans, these values would double.

Table 2 shows a second scenario in which 5 million acres of additional corn results from acreage shifts of crops other than soybeans. It is assumed that these will be lower yielding acres and therefore receive lower fertilizer rates than the acres coming from soybeans. Though enterprise budgets will likely influence which crops will contribute the acres, in this analysis the contributions are based on available acreage and an acreage-weighted average fertilizer rate calculated to subtract from the fertilizer applied to the new corn acres. Crops contributing acres were wheat, cotton, sorghum, and barley. Since the fertilizer rate differences between corn and the crops contributing the corn acres are smaller, the impact of this scenario on fertilizer use is less than when soybeans were contributing the new corn acreage.

Table 2. Impact of adding 5 million acres of corn taken from non-soybean crop acreage.

	Fertilizer use, 1,000 tons		
Change	N	P_2O_5	K_2O
+5 million acres of corn[1]	288	88	50
-5 million acres of crops[2]	169	58	37
Net	119	29	13
U.S. fertilizer use (04-06)	12,320	4,570	5,110

[1] Assuming lower corn yields (130 bu/A) receiving lower than average fertilizer use. (115+35+20, N+ P_2O_5+ K_2O, lb/A). N as 130 bu/A*1.2 lb/bu – 41=115.

[2] Based on Ag Chemical Use Survey acreage-weighted average fertilizer rates for winter wheat (0.53), cotton (0.23), sorghum (0.15), and barley (0.09).

Table 3. Nutrient content of corn stover.

	lb/dry ton		
Parameter	N	P_2O_5	K_2O
Range in 8 estimates of "typical"[1]	9-22	3.6-8.0	16-46.5
Average	19	5.7	32
	In 75 million tons of stover:		
1,000 tons	713	214	1,200
% of U.S. fertilizer use per year (04-06)	5.8	4.7	23

[1] U.S. and Canada sources

Table 4. Impact of changing from corn grain to corn grain + stover harvest.

	Removal, lb/A/yr		
Harvested portion	N	P_2O_5	K_2O
Grain, 150 bu/A	135	57	41
Stover, 3.5 t/A	67	20	112
Stover, 1.4 t/A[1]	27	8	45
Total (grain + 40% of stover)	162	65	86
Change, %	20	14	110

[1] Assuming 40% of stover can be removed sustainably. Estimates for average sustainable levels vary at least from 33 to 50%.

Harvest of Crop Residues and Energy Crops

The production of ethanol from cellulosic biomass occurs today only on a pilot basis, but progress is being made towards commercialization. If cellulosic ethanol production does become a commercial reality as many experts are predicting, the impact on the fertilizer industry and nutrient cycling could be large, especially for K. Corn stover is expected to be a major initial feedstock due in part to a plentiful supply, with current sustainable availability estimated at 75 million tons per year (Perlack et al., 2005). The nutrient content of this stover is difficult to predict due to the wide range in "typical" nutrient concentrations reported in the literature (**Table 3**). Nutrient content of stover entering a biorefinery could be even more variable due to variation in foliar leaching during crop senescence, extent of weathering in the field, or harvest techniques. For the calculations made in this paper, eight reported "typical" stover nutrient concentrations reported in the literature were simply averaged as shown in **Table 3**. Using these average figures, the 75 million tons of harvestable corn stover would contain nutrients equivalent to 6%, 5%, and 23% of annual U.S. fertilizer sales of N, P_2O_5, and K_2O, respectively.

Table 4 compares the nutrient removal in grain and stover for a 150 bu/A corn crop (average yield for U.S. for 2005 and 2006). Assuming that on average 40% of the stover can be harvested sustainably and maintain soil quality, stover harvest increases nutrient removal by 20, 14, and 110% for N, P_2O_5, and K_2O respectively over grain-only harvest.

Thinking in terms of biorefinery capacity helps visualize how a commercial cellulosic industry might get started. Though the bioenergy literature indicates considerable uncertainty in commercial scale details, an 80 million gallon refinery seems to be in the central range of the capacities presented as does an estimate of 80 gallons of ethanol per dry ton of stover (**Table 5**). Therefore, a reasonable estimate of the stover demand for a refinery is a million tons of stover…10 refineries would require 10 million tons per year or 6 to 7 million acres supplying corn stover.

Once cellulosic ethanol production is commercialized, energy crops such as switchgrass or miscanthus (elephant grass) are bound to enter the scene in short order. These are often described as "low input" species, not requiring fertilization or at most, minimal fertilization (Tilman et al., 2006). However, studies show these species are highly responsive to N fertilization (Muir et al., 2001; Sanderson et al., 2001) and can remove large quantities of nutrients, especially K (**Table 6**), though content is extremely variable. Rainfall during leaf senescence can markedly reduce plant K concentration.

At the assumed content of 46 lb K_2O/ton, 10 million acres of switchgrass yielding 8 tons/A would remove a quantity of K equivalent to 36% of total current U.S. fertilizer K

Table 5. Potential demand for corn stover for cellulosic ethanol production in U.S.

	Million acres at[2]		Removal, 1,000 tons		
Biorefineries[1]	1.4 t/A	1.8 t/A	N	P_2O_5	K_2O
10 (800 mil gal)	7.1	5.6	80	29	200
20 (1,600 mil gal)	14.2	11.2	160	58	400

[1] Assuming 80 million gallon biorefinery feasbile size; 80 gal/dry ton; 1 million tons stover/refinery (estimates range from 60 to 100 gal/ton).

[2] Assuming 40% or 50% of stover can be removed sustainably.

Table 6. Nutrient content of switchgrass.

Crop	Yield, tons/A	Fertilizer N, lb/A	Removal, lb/A N	P_2O_5	K_2O
Range in estimates[1]	1	–	13-28	4.5-13	12-66
Average	1	–	22	8.9	46
Low yield switchgrass	4	75[2]	88	36	184
High yield switchgrass	8	150[2]	176	72	368

[1]U.S. sources. [2]Typical N application rates.

Table 7. Reference points for the potential impact of biofuels on fertilizer use in the U.S.

	1,000 tons			% of annual U.S. fertilizer (04-06)		
Ethanol source	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Corn grain – 7.5 mil acres from soy[1]	701	119	102	5.7	2.6	2.0
Corn grain – 2.5 mil acres from non-soy crops[1]	60	15	7	0.5	0.3	0.1
10 refineries – stover (10 mil tons)[2]	80	29	200	0.6	0.6	3.9
Biomass crops, 10 mil acres, 6 t/A[3]	550	134	690	4.5	2.9	13.5
Total	1,391	297	999	11.3	6.5	19.5

[1]Net increase in fertilizer use.

[2]Nutrient removal; 16% of sustainably collectable stover based on 1995-2000 production with no change in tillage (Graham et al., 2007).

[3]Crops such as switchgrass or Miscanthus; 50% of removal for P and K; 110 lb N/A.

consumption. However, deep rooted perennial crops often do not receive nutrient applications at removal rates due to the soils they are sometimes grown on, the ability to tap soil nutrient reserves not measured in routine soil tests, and grower resistance to application of the large rates involved. Even if the content estimate is off by 50% and growers only replace 50% of the P and K removed, it's still a lot of nutrients that will be transported from the field to biorefineries.

The question remains of what large nutrient removal by biomass crops and crop residue harvest means to the fertilizer industry. At first glance, it appears to represent a potentially large increase in fertilizer demand following the logic that nutrients are being removed from fields that will indeed eventually need replacement. Yet when one considers the fate of the nutrients being removed, the vision of these removed nutrients as raw material for a new fertilizer source or sources appears. At least some of the N and P moving to biorefineries will very likely end up entering the livestock feed industry as is the case with grain-based ethanol production, but the K accumulating will have limited value for that use. It will go somewhere, and the likely place is back to production fields, but not necessarily the fields it came from.

It appears it would be wise for the fertilizer industry to further explore with the bioenergy industry the potential for partnerships based on the concept of biomass nutrients as fertilizer co-products. Early discussions, before commercialization, may be beneficial to allow consideration of how processes might be modified to accommodate fertilizer co-product production while also increasing ethanol production efficiency. Brazil learned long ago how to make a fluid fertilizer (venasse) from the nutrients resulting from processing of sugarcane into ethanol. Perhaps there is a corollary with cellulosic ethanol production.

A summary of reference points for the potential impact of biofuels on fertilizer use is offered in **Table 7**. It considers the March 30 USDA Prospective Plantings Report which indicated that corn plantings are expected to be 10.1 million acres above the 2004-2006 average and soybeans and cotton 7.1 and 2.3 million acres, respectively, below the 3-year average. This table does not include the impact higher crop prices and accelerated development of crop genetic potential might have on nutrient management across all planted acres, which of course could be quite large in itself. The across-the-table impact will likely be felt on both fertilizer product use and on the knowledge-based services associated with using those products effectively. Though corn to fertilizer price ratios are not greatly different today than they have been in the past, the economic penalty for over or underestimating need or for nutrient loss is much greater with $4 corn/$0.40 N than it was with $2 corn/$0.20 N. Economic justification for precision fertilizer application, fertilizer efficiency enhancement, soil testing, plant sampling, soil or plant imaging, on-farm strip trials, omission plots, and other forms of decision support is great indeed. Investing in determination of right source, rate, time, and place for plant nutrients is a low risk, high potential benefit proposition for both the pocket book and the environment.

The development and expansion of the biofuels industry may well mark the end of a 25-year era in agriculture – an era that was dominated by the mindset that production is a problem and input reduction is the solution. Perhaps, biofuels and the array of co-product opportunities that is appearing along with it offers a new mindset where sustainable development of the real potential of modern agriculture to harness the sun's energy in meeting food, feed, fiber, and fuel needs becomes the focus. Such a mindset is ripe with opportunity for agriculture provided the steps taken are not only good business moves, but grounded in science-based sustainable practices leading to efficient and effective nutrient management and resource utilization.

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Phosphorus Fertilizer Boosts Yields in Fallow Wheat Production

By Stewart A. Brandt

Phosphorus fertilizer addition over a 72-year period increased crop yields from 19 to 29% depending on the environmental conditions in each year.

The role that fertilizer has played in crop production has been reviewed in a number of past publications, and recently summarized by Stewart et al., 2005. The general consensus is that fertilizers contribute from 30 to 50% of crop production in most intensively cropped environments. However, the question is often asked: "What is the impact of fertilizer in less intensive environments?"

On the northern Great Plains, fallow remains a component of dryland cropping systems (Zentner and Campbell, 1988). While not very efficient, the fallow period contributes to soil moisture conservation which allows for substantial increases in crop yields under very dry environments. When grown on fallow, most crops in this region respond to fertilizer P additions. These responses are due to low soil P in most of these calcareous soils, and cool soil temperatures at seeding.

A long-term fallow/wheat/wheat rotation study was conducted at Scott, Saskatchewan, to monitor year-to-year crop yields, and to evaluate soil quality changes. After 72 years of cropping (1930 to 2002) in a fallow/wheat/wheat rotation, the yields on fallow were evaluated based on growing season precipitation. The 24 driest years (May-July precipitation averaging 4.25 in.), 24 near normal years (May-July precipitation averaged 6.25 in.), and the 24 wettest years (May-July precipitation averaged 8.36 in.) were compared for the response of spring wheat to P fertilizer additions of 30 lb P_2O_5/A.

The largest percentage gain in yield was achieved during dry years, declining slightly for both near normal and wet seasons (**Table 1**). Given the mineralization of N during the fallow period on these soils, no fertilizer N was applied and no response to N was expected. The grain yield response to fertilizer P additions, ranging from 19 to 29%, is less than that reported in earlier publications and reflects on this mineralized soil N. While farmers often consider reducing inputs during dry years, these results suggest that fertilizer P may be an exception. Adequate P from fertilizer may be essential for efficient water use during dry seasons.

Phosphorus was applied to the area at left in this photo showing wheat response.

Table 1. Crop yield response to fertilizer P addition to wheat grown on fallow.

Treatment	Check, bu/A	P added, bu/A	Gain, bu/A	Gain, %
24 driest years	18.7	24.1	5.4	29
24 average years	24.1	28.6	4.5	19
24 wettest years	31.2	38.7	7.5	24

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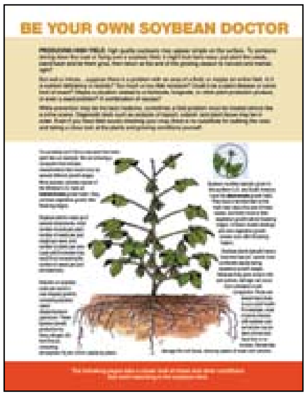
Abbreviations and notes for this article: P = phosphorus; N = nitrogen.

Introducing: *Be Your Own Soybean Doctor*

A new publication from IPNI titled *Be Your Own Soybean Doctor* offers soybean growers and their advisers and consultants a new tool. The 8-page booklet features over 40 color illustrations showing typical symptoms of nutrient deficiencies, toxicities, diseases, insect damage, and other disorders in soybean production. While it does not substitute for diagnostic tools such as plant tissue analysis and soil testing, this publication can help distinguish and identify various field problems.

The 8½ x 11-in. guide is patterned after the classic publication *Be Your Own Corn Doctor* and the more recent *Be Your Own Cotton Doctor*, both widely used in the field.

Be Your Own Soybean Doctor is available for US$0.50 (50 cents) each, plus shipping. Discounts on quantity orders. Contact: Circulation Department, IPNI, phone 770-825-8082, fax 770-448-0439. E-mail: circulation@ipni.net or check the website: >**www.ipni.net**<.



BE YOUR OWN SOYBEAN DOCTOR

Spatial Variability and Site-Specific Nutrient Management in a Vegetable Production Area

By Shao-Wen Huang, Ji-yun Jin, Ping He, Li-Ping Yang, and You-lu Bai

Soil nutrients showed similar spatial distribution patterns across the study site in Hebei Province and were correlated with vegetable production history and fertilizer application rates. Vegetable crop type and history of fertilizer use were important factors in the development of a regional nutrient management program.

A long-term reliance on high rates of N and P fertilizer along with a poor understanding of soil nutrient variability within fields can seriously affect vegetable yield and quality, economic income, and environmental quality in China. During the last 10 years, data obtained from GPS/GIS and geo-statistics has played an important role in the study of soil nutrient spatial variability and SSNM (Jin, 1998). Recent examples of this type of research exist for grain production systems within China (Huang et al., 2003; Huang et al., 2004).

However, spatial variability in China's vegetable fields and corresponding management approaches have not been studied systematically. China's vegetable production system is more intensive and farmers generally use higher rates of fertilizer compared to grains. The objective of this study was to analyze the spatial variability of soil nutrients as a basis for SSNM strategies for high quality and high yield vegetable production.

The study was located in the northwestern vegetable production area of Taizhang Village, Hongqiao Town, Yutian County. The soil at the site is classified as Fluvo-aquic—a floodplain soil. The most limiting soil nutrients included N, K, and Zn (**Table 1**). Only 5% of the soils had P contents below the critical value, but emphasis on P fertility was still recommended due to high crop P requirements and the need to maintain high soil P fertility. The local climate was semiarid monsoon, with an average annual rainfall of 693 mm, average annual temperature of 11 °C, and a frost-free period of about 190 days annually. In recent years, cabbage has generally been grown as the first crop in this area from March to May, with many other kinds of vegetables being grown as the second crop each year. The most common rotation systems included cabbage/welsh onion, cabbage/Chinese cabbage, cabbage/Chinese celery, and cabbage/leaf mustard.

The study area consisted of 182 farmer plots belonging to six production groups. These are denoted further in this report as Groups 1, 2, 3, 4, 7, and 8, respectively (**Figure 1**). Groups 1, 2, 3, 4, 7, and 8 consisted of 29, 35, 27, 31, 37, and 23 farmer plots, respectively. A total of 217 soil samples were collected on a 50 m × 50 m grid at depths of 0 to 20 cm prior to the plots being sown for cabbage. Vegetable production history was surveyed at each sampling site, including crop types sown, rotation systems, and fertilizer use. Soil pH, OM, and available P, K, Cu, Fe, Mn, Zn, Ca, Mg, S, and B were analyzed according to the Agro Services International (ASI) soil test procedure (PPIC Beijing Office, 1992). Soil NO_3^--N and particle size were also measured (Huang et al., 2004). Cabbage response to site-specific balanced fertilization under different soil fertilizer levels was determined. Descriptive statistics and geo-statistics were used to analyze the data.

Results showed significant similarity in the spatial distribution of soil NO_3^--N, P, K, and Zn in the study area (**Figure 2**). Correlation coefficients between soil NO_3^--N content and soil P, K, and Zn contents were 0.47, 0.46, and 0.24 ($p<0.01$), respectively. Correlation coefficients between soil P and soil K and Zn contents were 0.76 and 0.52 ($p<0.01$), respectively. The correlation coefficient between soil K content and soil Zn content was 0.49 ($p<0.01$).

Significant differences in soil fertility existed between production groups (**Table 2**).

Table 1. Soil OM, available nutrient, sand, and clay contents, and pH in the vegetable production area.

Item	Minimum	Maximum value	Mean	Standard deviation	C.V., %	Critical value	Soil samples below critical value, %
pH	5.1	7.9	6.7	0.64	10		
OM, %	1.0	2.3	1.8	0.2	10	1.5	2
NO_3^--N, mg/L	20	156	63	28	44	60	53
P, mg/L	4	94	35	16	47	12	5
K, mg/L	44	147	75	20	27	80	67
Zn, mg/L	0.6	3.9	1.43	0.43	30	2	93
Mn, mg/L	3	71	18	12	70	5	8
Fe, mg/L	3	65	16	11	69	10	36
Cu, mg/L	1.0	3.3	1.86	0.42	23	1	0
S, mg/L	7	75	36	13	37	12	4
Ca, mg/L	2,796	5,753	4,429	499	11	401	0
Mg, mg/L	393	934	721	109	15	122	0
B, mg/L	0.3	8.0	2.35	1.35	57	0.2	0
Sand, %							
0.02-2 mm	24	35	28	2	6		
Clay, %							
<0.002 mm	23	35	28	2	8		

217 sampling sites were evaluated

Abbreviations and notes for this article: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Ca = calcium; Mg = magnesium; Zn = zinc; Cu = copper; Fe = iron; Mn = manganese; B = boron; NO_3^--N = nitrate-N; NH_4^+ = ammonium; GPS = global positioning system; GIS = geographic information system; OM = organic matter; SSNM = site-specific nutrient management; CV = coefficient of variation; FP = farm practice.

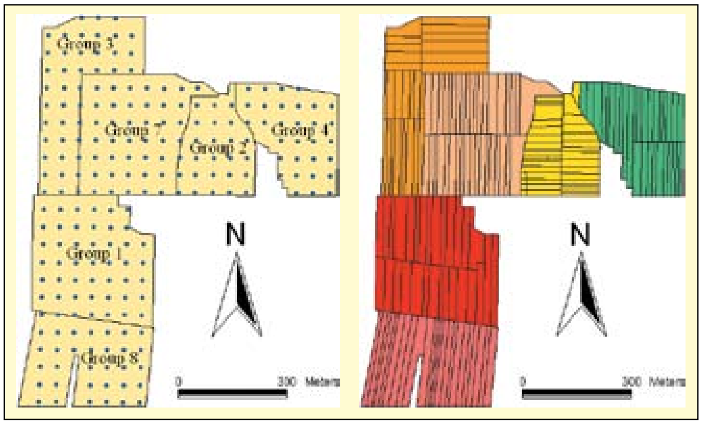


Figure 1. Diagram of sampling sites within production groups (left) and farmers' plots (right) in the vegetable production study area.

Soil NO_3^--N, P, K, and Zn within Groups 2 and 7 were significantly higher than in Group 8. Nutrient levels within most areas of Groups 1, 3, and 4 were also lower compared to Groups 2 and 7. Our farm surveys indicated that a close relationship existed between the spatial variability of soil nutrients and the vegetable production history and fertilizer application. Statistical analysis found a close, positive correlation for soil NO_3^--N, P, and K contents and N, P_2O_5, and K_2O fertilizer application rates, with the corresponding correlation coefficients as high as 0.50, 0.47, and 0.45 ($p<0.01$), respectively. Nitrogen application rate was negatively correlated with soil pH ($r = -0.31$, $p<0.01$). The hydrolysis of applied N forms, such as urea, produces NH_4^+ which is subject to nitrification and the release of hydrogen ions (H^+) (Fisk and Schmidt, 1996). Thus the lower pH for Groups 2 and 7 compared to Group 8 is one other characteristic developed from longer vegetable production history and higher and larger N fertilizer applications. A decline in soil pH can also increase soil Zn availability, a relationship which is supported by the map and statistical data for this study area.

The higher contents of soil NO_3^--N, P, and K for Groups 2 and 7 compared to Group 8 corresponded with longer vegetable production histories and higher and more frequent fertilizer applications (**Table 3**). Groups 2 and 7 had grown vegetables for 18 to 19 years, while vegetables had been grown for only 7 years within Group 8. Prior to this time, wheat and corn were the main crops, with relatively smaller annual application rates (Huang et al., 2002). Higher soil fertility for plots within Groups 2 and 7 versus Groups 1, 3, and 4 is most likely a result of higher planting frequencies for welsh onion or Chinese celery as second crops after the primary cabbage crop. Welsh onion and Chinese celery both require higher nutrient inputs than other vegetables grown in the region (**Table 4**).

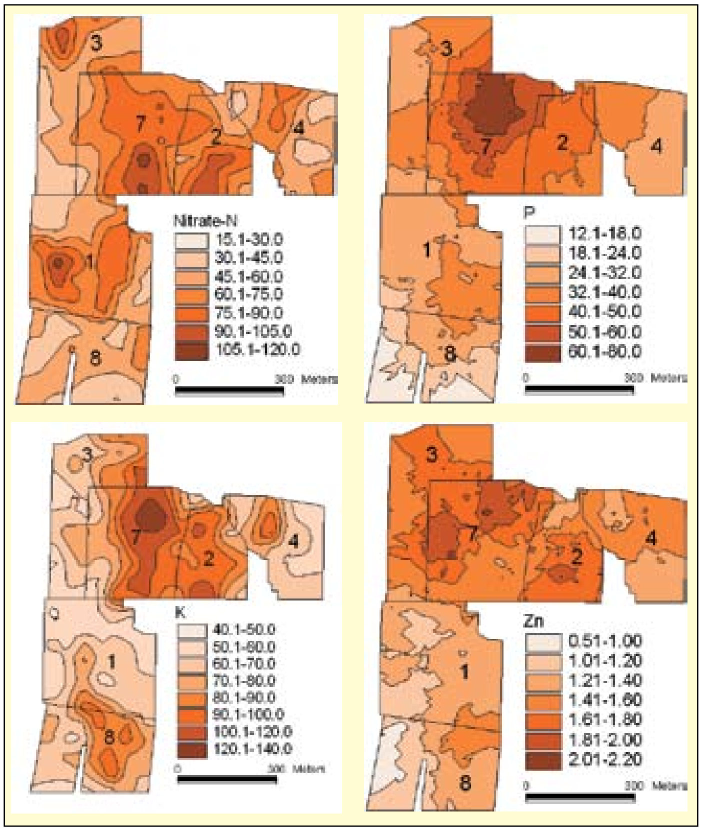


Figure 2. Overlay between the map of the production groups and the contour map of soil-available nutrients (mg/L) in this study area (1, 2, 3, 4, 7, and 8 indicate the respective production group). The boundary for each group can be seen from Figure 1.

Fertilizer use, soil nutrient status, vegetable production history, vegetable variety, and soil texture were found to be important factors in establishing a regionalized system for managing soil nutrients. Of these, the first three in the list showed

Table 2. Average soil OM, available nutrient, sand, and clay contents, and soil pH in the six production groups of the vegetable production area.

Item	Group 1 N = 45	Group 2 N = 25	Group 3 N = 42	Group 4 N = 31	Group 7 N = 40	Group 8 N = 34
pH	6.9±0.3 d	6.6±0.4 c	6.3±0.5 b	6.4±0.4 bc	6.1±0.4 a	7.6±0.2 e
OM, %	2.0±0.1 c	1.7±0.2 a	1.8±0.2 b	1.6±0.1 a	1.8±0.1 b	2.0±0.2 c
NO_3-N, mg/L	66±31 bc	72±28 cd	55±24 a	56±24 ab	80±24 d	45±19 a
P, mg/L	30±9 b	42±15 c	33±12 b	31±10 b	52±17 d	20±12 a
K, mg/L	63±13 a	92±16 c	69±15 ab	67±15 ab	93±23 c	74±15 b
Zn, mg/L	1.2±0.3 ab	1.6±0.4 d	1.5±0.4 cd	1.4±0.4 bc	1.6±0.5 d	1.2±0.3 a
Mn, mg/L	14±7 b	18±9 bc	22±12 cd	20±10 c	26±16 d	5±2 a
Fe, mg/L	11±3 b	14±8 b	20±9 c	19±9 c	25±14 d	5±3 a
S, mg/L	37±13 b	40±13 bc	26±13 a	44±11 c	38±7 b	35±15 b
Sand, % 0.02-2 mm	27.1±1.4 a	28.3±2.0 b	27.1±1.2 a	28.8±1.2 b	27.2±1.6 a	27.3±1.5 a
Clay, % <0.002 mm	28.3±1.6 de	27.0±2.0 bc	28.6±2.0 e	25.7±1.1 a	27.6±1.9 cd	26.7±2.9 ab

* Means with the same letter are not significantly different at $p<0.05$ (lower case letter). ± = standard deviation.

significant differences between production groups. However, no obvious differences in vegetable production history, first and second vegetable crop selection, fertilizer use, soil nutrient status, and soil texture were found within production groups. Thus, it was technically feasible to develop SSNM strategies for balanced N, P, K, and Zn application at the production group-scale.

SSNM techniques for high-yield and high-quality vegetable production were developed based on GIS maps and a computerized fertilizer recommendation system (IPNI China Program, 2007). Fertilizer recommendations for a production group or farmer's plot were accomplished via information transmission, long-distance diagnosis, and online consultation. A nutrient fertility class for each production group or each farmer's plot could be obtained by overlaying the contour map of soil nutrients with either the map of the production groups (**Figure 1**, left) or farmer plots (**Figure 1**, right) in the GIS. If soil nutrient contents in most areas of a production group or plot were within one evaluation class, soil nutrient contents for all areas of that group or plot were considered to fall within that one evaluation class. A fertilizer recommendation was made according to production group or plot, and variable fertilization was performed by farmers through hand application. SSNM treatments applied significantly less N and P than FP, and utilized Zn which was omitted under FP.

Table 3. Vegetable production history and average fertilizer application rates for the period 2000-2002 for each production group of the vegetable production area.

Production group	Number of plots surveyed	Production history in years	Fertilizer application rate, kg/ha/year					
			Chemical fertilizer			Organic manure		
			N	P_2O_5	K_2O	N	P_2O_5	K_2O
Group 1	29	15.5±0.7	957 ±217	275 ±90	276 ±90	16 ±30	12 ±23	11 ±21
Group 2	35	18.6±1.0	1019 ±220	358 ±88	358 ±87	0.0 ±0.0	0.0 ±0.0	0.0 ±0.0
Group 3	27	16.0±1.1	946 ±190	288 ±87	288 ±87	26 ±74	19 ±56	21 ±62
Group 4	31	17.6±0.5	909 ±220	345 ±146	309 ±93	4 ±24	3 ±18	4 ±20
Group 7	37	19.4±0.9	1124 ±228	420 ±95	420 ±95	14 ±41	10 ±31	11 ±34
Group 8	23	7.1±1.3	813 ±218	267 ±93	315 ±112	21 ±38	16 ±28	16 ±31

* Correlation coefficients between soil NO_3^--N, P, and K contents and total application rates of N, P_2O_5, and K_2O in chemical fertilizer and organic manure were 0.50, 0.47, and 0.45 ($p<0.01$, n = 217), respectively. ± = standard deviation.

Table 4. Average fertilizer input in main vegetables for the period 2000-2002.

Vegetable varieties	Number of plots surveyed	Average fertilizer application rate, kg/ha/year		
		N	P_2O_5	K_2O
Cabbage	182	412±74	123±33	123±34
Welsh onion	64	640±210	244±92	238±81
Chinese cabbage	41	318±122	74±52	74±52
Chinese celery	41	688±219	214±147	222±154
Leaf mustard	36	210±93	52±16	52±16

Cabbage was grown as the first crop in this study area consisting of 182 farmer plots. Other kinds of vegetables were grown as the second crop each year.
± = standard deviation.

Table 5. Response of site-specific balanced fertilization in cabbage in 2004.

Fertility category	Treatment	Yield (fresh weight), t/ha	Yield increase, %	Fertilizer input, RMB yuan/ha	Fertilizer input decrease, %	Income, RMB yuan/ha	Income increase, %
Relatively high soil fertility	Farm practice $N_{365.7}P_{135.0}K_{135.0}Zn_{0.0}$	64±2.7	–	2,052	–	18,412	–
	Balanced fertilization $N_{300.0}P_{45.0}K_{105.0}Zn_{30.0}$	69.7±1.5	9.0±2.4	1,485	27.6	20,827	13.1
Medium soil fertility	Farm practice $N_{465.0}P_{157.7}K_{148.4}Zn_{0.0}$	68.4±1.6	–	2,493	–	19,406	–
	Balanced fertilization $N_{330.0}P_{75.0}K_{135.0}Zn_{30.0}$	77.3±2.5	13.0±3.3	1,780	28.6	22,969	18.4
Relatively low soil fertility	Farm practice $N_{473.8}P_{157.6}K_{158.0}Zn_{0.0}$	64.1±2.7	–	2,545	–	17,958	–
	Balanced fertilization $N_{375.0}P_{105.0}K_{165.0}Zn_{30.0}$	74.2±3.0	16.0±2.0	2,122	16.6	21,654	20.6

N, P, K, and Zn, respectively denote N, P_2O_5, K_2O, and $ZnSO_4{\cdot}7H_2O$, with subscript numbers being application rate of nutrient or fertilizer (kg/ha). Price of N, P_2O_5, K_2O, $ZnSO_4{\cdot}7H_2O$, and cabbage is 3.15, 4.17, 2.50, 3.00, and 0.32 RMB Yuan/kg, respectively. ± = standard deviation. 1 US$ = 7.7 RMB.

Table 6. Recovery rate of the applied N for site-specific balanced fertilization in cabbage in 2004.

Fertility category	Treatment	N uptake, kg/ha	N contribution from soil, kg/ha	Recovery rate for applied N, %
Relatively high soil fertility	Farm practice $N_{365.7}P_{135.0}K_{135.0}Zn_{0.0}$	129±6	100±4	7.9±0.9
	Balanced fertilization $N_{300.0}P_{45.0}K_{105.0}Zn_{30.0}$	149±3	95±4	18.0±2.2
Medium soil fertility	Farm practice $N_{465.0}P_{157.7}K_{148.4}Zn_{0.0}$	139±3	114±4	5.4±1.2
	Balanced fertilization $N_{330.0}P_{75.0}K_{135.0}Zn_{30.0}$	155±5	101±4	16.4±2.0
Relatively low soil fertility	Farm practice $N_{473.8}P_{157.6}K_{158.0}Zn_{0.0}$	140±6	107±4	7.0±1.8
	Balanced fertilization $N_{375.0}P_{105.0}K_{165.0}Zn_{30.0}$	170±7	107±4	16.8±3.0

The contributed N from soil denotes plant N uptake from no N treatment (FP - N for FP, BF - N for BF).

± = standard deviation.

Yield, profitability, and N recovery rate data for FP and SSNM are compared within the high, medium, and low soil fertility plots in **Table 5** and **Table 6**. SSNM increased cabbage yield by 9, 13, and 16% within high, medium, and low fertility plots, respectively. SSNM also lowered fertilizer input costs by 27.6, 28.6, and 16.6% (high, medium, and low), and improved income per hectare by 13.1, 18.4, and 20.6% (high, medium, and low).

Plant N uptake was enhanced under SSNM at all three soil fertility classifications. SSNM employed lower N application rates, and the contribution from other soil N pools was relatively equal between plots receiving SSNM and FP. Thus, significant improvements in N recovery rate, ranging between 9.8 to 11 percentage points, were achieved across soil fertility classifications. BC

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InfoAg 2007 Set for July 10-12 in Springfield, Illinois

The popular national/international version of the Information Agriculture Conference, InfoAg 2007, is scheduled for July 10, 11, and 12. The location is the Crowne Plaza in Springfield, Illinois, the same as for InfoAg 2005.

InfoAg 2007 is organized by the Foundation for Agronomic Research (FAR) in cooperation with IPNI. CropLife Media Group is also a partner in the Information Agriculture Conference, particularly with managing the exhibit area.

"The Information Agriculture Conference has come a long way since the first conference in 1995," notes FAR President Dr. Harold Reetz, of Monticello, Illinois. "Many of the precision ag technologies that were considered to be in early development stages then are becoming generally adopted by farmers, dealers, and industry today."

Opportunities and effects of shifting corn production to meet the grain and biomass ethanol market demands is a hot topic in agricultural circles today, and will be part of the discussion at InfoAg 2007. The detailed records and natural resource (soil, water, etc.) inventories that are part of farm databases, and the other technologies of precision ag might be useful in decisions on shifting crop acreage. Many farmers and their advisers are also dealing with questions regarding how to manage continuous corn, or how to manage corn where they have not grown it before.

Another important question regards the issues of productivity: "How can we use these technologies to increase corn yields on our best fields and thus reduce the need to convert acreage from other crops, or from CRP?" That is the longer-term solution that will be addressed.

Conservation of natural resources will also be a major theme at InfoAg 2007. The Natural Resources Conservation Service (NRCS) will bring a large soil survey exhibit that was originally prepared for the 2006 World Congress of Soil Science in Philadelphia. The program will also feature a series of USDA-NRCS Conservation Innovation Grant projects that FAR and IPNI are coordinating to develop fertilizer best management practices guides for six major cropping systems.

A pre-conference tour and demonstration program will again be a feature of InfoAg 2007. Potential attendees and exhibitors for the Information Agriculture Conference are encouraged to plan ahead now in making arrangements. For more information about InfoAg 2007, please visit the website: >**www.infoag.org**<, or contact Dr. Harold Reetz: phone 217-762-2074, e-mail: hreetz@farmresearch.org. BC

Corn Response to Intensive Crop Nutrition

By Bill Deen, John Lauzon, and Tom Bruulsema

A 5-year study of a corn/soybean rotation in Ontario, Canada, shows that increasing inputs above recommended levels significantly increases yield and changes physiology. Transforming physiological changes into economically and environmentally sustainable yield increases will require further research.

Rising global needs for food, fuel, and fiber are driving up the demand and prices for corn. At the same time, the world's people want to limit the impact of cropland on the natural environment, both by limiting the expansion of cropland and the effects of crop production on water quality. These goals require research exploring intensive management for increased yields.

For the past 5 years, we monitored a corn/soybean rotation with varied management levels in a producer's field in south-central Ontario. Our objective was to assess changes in yield and physiology in response to intensive management and its interaction with high rates and deep placement of K fertilizer. Part of the goal was to determine the feasibility of manipulating input levels to increase yields closer to the genetic potential of current corn hybrids.

The main hypothesis we wanted to test was whether response to higher K inputs would increase with higher overall input levels and yields. The trial consists of seven management combinations: three varying K rates at the producer's level of inputs (which are generally close to recommended practices for Ontario), and four at an intensive input level, varying both K rates and placement of P and K fertilizers. Details of the applied treatments are shown in **Table 1**.

The soil is a London loam with good drainage. Soil pH was 7.5, and soil test P and K levels were 8 ppm Olsen P (low), and 107 ppm ammonium-acetate extractable K (medium). The first five treatments used the same conservation tillage practice of the producer: fall chisel plow with spring secondary tillage. The last two treatments used fall zone tillage followed by spring zone tillage. All plots consisted of strips the full length (1,000 to 1,500 feet) of the field; eight rows wide, with two hybrids in each: Northrup King 3030 Bt and Pioneer 38A25. The site was rated as having 2850 Ontario Crop Heat Units, roughly equivalent to 1,800 growing-degree-days.

For the field scale research on sustainable intensification, this photo of 2004 harvest shows an AGCO R42 combine equipped with a Juniper Systems Inc. High Capacity Grain Gauge.

Yield increases in response to the management levels imposed were modest. While the differences were significant statistically ($p<0.05$) and indicated interesting changes in corn physiology, no combination of input intensity and K rates was more economically viable than the producer's current level of management (treatment 2), even with the high corn prices prevailing in early 2007. Nevertheless, average yields at the high K level were consistently higher than those at the grower's K level over all 5 years (**Figure 1**).

The intensive treatments produced higher yields than the control (**Figure 2**). Differences were largest in the third and fifth years. While both K and input intensity generally increased yields, we found no evidence of interaction between the two factors. There was no greater requirement for K with higher input intensity.

Averaged over the 5 years, fall zone tillage did not differ from fall chisel plowing, but in 2004 it produced lower yields and in 2005, higher yields (**Figure 2**). This interaction with years indicates that the relative benefit of tillage method and nutrient placement depends on the growing season.

While we have not yet been able to assess the full environmental impacts, the intensive treatments did not result in higher soil residual NH_4^+ and NO_3^- levels following the 2006 harvest (**Table 2**). Treatment means were not significantly different at

Table 1. Fertilizer, seed, and tillage management treatments applied for corn.

	Fertilizer N-P_2O_5-K_2O, lb/A					
Treatment	Fall	Seed-placed	Starter	Side-dress	Total	Seeds per acre
1. Control, zero K	–		10-50-0	120-0-0	130-63-3	
2. Control, grower K			10-50-27		130-63-30	30,000
3. Control, high K	0-0-150^1				130-63-180	
4. Intensive, grower K	0-117-0^1	3-13-3			250-180-30	
5. Intensive, high K	0-117-150^1				250-180-180	
6. Intensive, zone-till, grower K	0-117-0^2		36-50-27	210-0-0	250-180-30	40,000
7. Intensive, zone-till, high K	0-117-150^2				250-180-180	

^{1} Broadcast before fall chisel plow tillage to 6 in. depth. ^{b} Placed 10 in. deep with fall zone tillage.

Abbreviations and notes for this article: K = potassium; P = phosphorus; ppm = parts per million; N = nitrogen; NH_4^+ = ammonium; NO_3^- = nitrate.

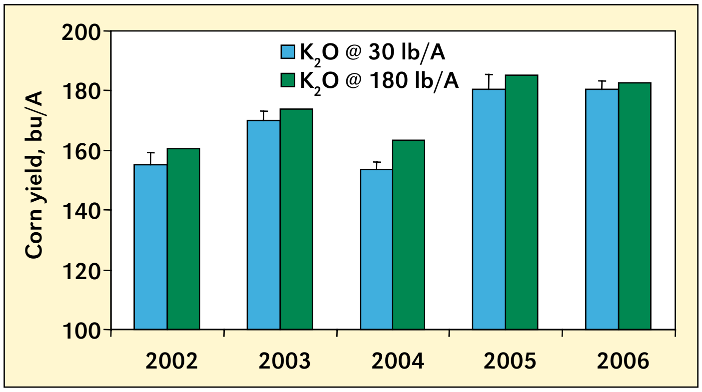

Figure 1. Corn yields at 30 and 180 lb K$_2$O/A, over 5 years.
Error bars represent least significant difference at the 5% level of probability.

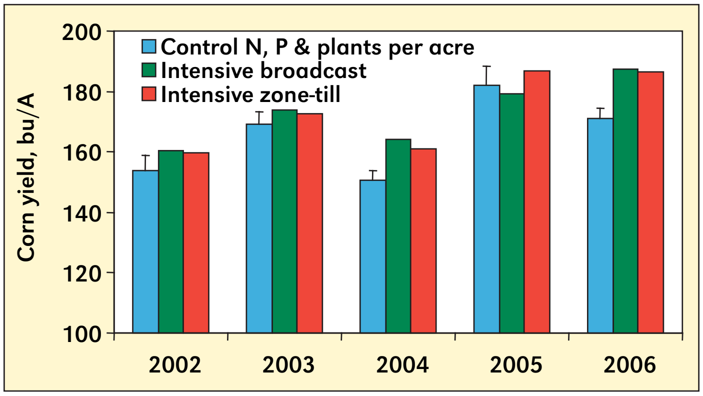

Figure 2. Corn yields with control and intensive input levels, over 5 years.
Error bars represent least significant difference at the 5% level of probability.

the 5% level. Considering the higher N rates of the intensive management levels, it is surprising that, first, so little available N was recovered in the top 18 in. of the soil, and second, that differences between management levels were not seen. The soil of this site is well-drained, and it is probable that some NO_3^- was lost by leaching, and the abnormally high rainfall in the fall of 2006 may even have made a major denitrification event a possibility.

Grain and stover N were essentially not influenced by treatments, averaging 1.41% and 0.89%, respectively, on a dry matter basis. Stover NO_3^- levels, however, increased significantly in response to K, intensive inputs, and zone tillage (**Table 2**). In 2006, grain moisture was significantly ($p<0.0001$) higher (25% vs. 24%) in the zone-tilled treatments compared to chisel-plowed.

The reason for the increased stover NO_3^- in response to K is not clear. The observed effects on stalk NO_3^- and grain moisture suggest differences in plant physiology and nutrient uptake patterns. Reduced lodging observed in the high K corn suggests better stalk integrity and less opportunity for loss of NO_3^- from the stalk by leaching. A slight delay in maturity in response to K may offer less susceptibility to loss of NO_3^- from stalks. Also, luxury uptake of K may induce increased uptake of NO_3^- as a counter-ion for charge balance. We measured root distributions, but did not observe any differences in response to applied K. However, it is possible that root system function may have been improved at higher levels of K.

Table 2. Residual N in soil and stover following the 2006 corn harvest.

Treatment	Soil residual N, lb/A[1]	Stover nitrate, ppm
1. Control, zero K	28	67
2. Control, grower K	33	228
3. Control, high K	34	448
4. Intensive, grower K	33	402
5. Intensive, high K	33	685
6. Intensive, zone-till, grower K	39	622
7. Intensive, zone-till, high K	33	772

[1] NH_4-N and NO_3-N in soil to 18 in. depth, sampled October 27, 2006.

Soil test levels have changed little where P and K inputs were at the producer's rates, but have increased significantly where higher rates were applied (**Table 3**). These rates resulted in net surpluses of P and net deficits of K over three crops of corn and two of soybeans, but neither had much influence on soil test levels. At the high rate of each nutrient, however, soil test levels have increased to the point where further soil test building is unlikely to benefit either corn or soybeans. About 30 lb/A of surplus P_2O_5 was required to increase soil test P by one ppm, and about 8 lb/A of surplus K_2O to do the same for soil test K. Soil test changes in the zone-tilled treatments differ, since the samples (collected 8 in. from the rows) only partly reflect the nutrient availability, owing to concentration of nutrients in the rows.

The University of Nebraska's Hybrid-Maize model predicts that the solar radiation and temperature regime for this site would result in a median potential corn yield of 191 bu/A, assuming no limitations from water or fertility. The intensive inputs of N, P, and K and increased plant population increased yields, but only by a small fraction of the gap between current and potential yields. Continued research is being planned, with changes in corn hybrids and other factors to determine whether the changes in soil fertility and quality accumulating over time can be exploited to greater benefit for sustainable productivity.

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Table 3. Soil test levels and nutrient balance following the 2006 corn harvest.

	Soil test, ppm		Nutrient balance, lb/A[1]	
Treatment	P	K	P_2O_5	K_2O
1. Control, zero K	10	76	50	-190
2. Control, grower K	9	77	50	-70
3. Control, high K	7	140	20	500
4. Intensive, grower K	26	91	470	-110
5. Intensive, high K	22	145	460	490
6. Intensive, zone-till, grower K	21	80	490	-100
7. Intensive, zone-till, high K	17	119	490	500

[1] Nutrients applied over 5 years minus nutrients removed in grain from 3 corn and 2 soybean harvests.

Sulfate of Potash Foliar Spray Effects on Yield, Quality, and Post-Harvest Life of Banana

By A. Ramesh Kumar and N. Kumar

The benefits of applying foliar K included increased fruit bunch yields and enhanced physical and market quality traits. Foliar spray in the form of SOP could be economically integrated into banana nutrition strategies.

Banana requires large amounts of nutrients for proper growth and production. Its nutritional requirement is estimated to be around 320 kg N, 32 kg P_2O_5, and 925 kg K_2O/ha per year (Lahav and Turner, 1983). Neypoovan is one of the leading banana cultivars of southern India. Yet, poor filling and development of fruits is often reported with this cultivar, which might be related to inadequate nutrients or non-availability just prior to the shooting stage occurring 7 months after planting. High nutrient availability is important at that stage to support plant requirements until harvest since large quantities of photosynthates are beginning to move from the source to the sink—developing fruit bunches. Any limitation in the supply of nutrients at this time will negatively affect bunch size and quality. However, it has not been wise to apply fertilizers basally at finger development stage, since the uptake is slow and low (Veerannah et al., 1976; Buragohain and Shanmugavelu, 1986).

Many reports have indicated usefulness for a post-shoot stage spray of various nutrients in influencing fruit yield, shelf life, and quality (Kannan, 1980; Swietlik and Faust, 1984). Banana responds well to foliar spray supplied through KCl or KH_2PO_4 (Yoharathnam et al., 1981; Mahalakshmi and Sathiyamoorthy, 1999). However, the effect of foliar SOP spray has not been assessed. An investigation was carried out at Tamil Nadu Agricultural University (TNAU), Coimbatore, with the objectives of: 1) evaluating the effect of post-shooting stage spray of SOP on bunch yield and quality of banana, and 2) integrating SOP into the nutrient management practices of regional banana farms.

The experiment was conducted with Neypoovan banana, using a randomized block design with four treatments (**Table 1**). Plants were sprayed twice, initially after the opening of the last hand (i.e. 7th month after planting), and 30 days later. The entire plant canopy was sprayed including the developing bunches. Due to the waxy nature of the leaf surface, a wetting agent (APSA 80) was included at 2 ml per 10 L of spray solution.

Banana plant in bearing stage, sprayed with SOP.

Study parameters included: the total number of leaves retained at harvest, total leaf chlorophyll content, days to maturity, bunch weight, and the total number of hands and fingers per bunch. The middle fingers in the top and bottom rows of the second hand were selected to record average finger weight, girth, and length. Fully ripened fruit were selected to record fruit pulp:peel weight ratios. Quality parameters included TSS, total, reducing and non-reducing sugars, titrable acidity (expressed as malic acid equivalents), sugar:acid ratio, and the PLW of fruits. The cost of cultivation accounted for various inputs during the entire experimental period. Net returns were also determined for each treatment.

Foliar SOP spray significantly increased the number of leaves at harvest, with leaf number being highest in the 1.5% SOP treatment (**Table 1**). Lahav, 1972; Mustaffa, 1987; and Baruah and Mohan, 1991, indicate that reduced longevity of banana leaves can be due to high mobility of K from old leaves to other plant parts, and as a result, leaf duration can be severely hampered by low K content. In the present investigation, the relative decrease in leaf number at harvest was low in plants

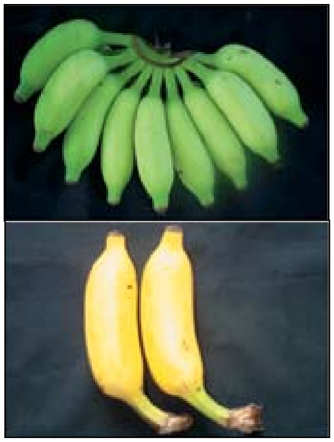
Table 1. Effect of SOP foliar spray on number of leaves at harvest, total chlorophyll, and bunch traits of banana.

Treatment	Number of leaves	Total chlorophyll, mg/100g	Maturity days	Bunch weight, kg	Number of hands	Total number of fingers
Control (Water)	8.0	1.517	110.4	10.80	11.17	182.3
0.5% SOP spray	8.4	1.672	105.5	11.53	12.33	209.0
1.0% SOP spray	8.2	1.702	100.3	12.63	13.00	221.0
1.5% SOP spray	10.2	1.769	89.9	14.27	13.00	233.3
SEd	0.168	0.075	2.82	0.50	0.253	4.30
CD (p=0.05)	0.344	0.155	5.77	1.02	0.517	8.79

Abbreviations and notes for this article: SOP = sulfate of potash (potassium sulfate); KCl = potassium chloride; KH_2PO_4 = potassium di-hydrogen phosphate; TSS = total soluble solids; PLW = physiological loss in weight.

Table 2. Effect of SOP foliar spray on various finger traits of banana.

Treatment	Finger length, cm	Finger girth, cm	Finger weight, g	Pulp weight, g	Peel weight, g	Pulp:peel ratio
Control (Water)	10.33	9.50	55.7	49.7	7.2	6.90
0.5% SOP spray	10.97	10.33	67.7	59.5	8.2	7.26
1.0% SOP spray	12.83	12.07	71.4	62.4	8.5	7.33
1.5% SOP spray	14.37	13.77	75.1	65.7	8.9	7.38
SEd	0.57	0.41	4.58	3.67	0.67	0.097
CD (p=0.05)	1.17	0.83	9.36	7.50	1.37	0.198



Second hand from SOP-sprayed bunch at top. Below: Fingers from SOP-sprayed bunch.

receiving foliar spray. The synthesis and transport of plant assimilates to the developing banana fruit is greatly affected by the retention of green leaves after the flowering stage, especially when assimilate flow from other plant parts becomes limiting. Senescing leaves also contribute their own stored assimilates to developing fruit.

Neypoovan plants receiving foliar spray had significantly higher leaf chlorophyll content at harvest. Retention of chlorophyll pigment during the post-shooting growth stage helps fruit bunches accumulate photosynthates, thus contributing to fruit bunch size, days to maturity and yield. Potassium is a general metabolic activator, increasing the respiration and photosynthetic rate (Evans, 1971; Martin-Prevel, 1972).

Improvements in fruit bunch weight and yield are the culmination of all desirable traits that perform well under optimum conditions including balanced nutrition. Foliar spray concentration had a significant and positive impact on bunch weight. Fruit bunch components including: hand and finger number, finger length, girth, and weight, were positively impacted by treatment with foliar spray (**Table 2**). Perceptible differences among spray concentrations were also realized for the fruit pulp:peel ratio. Improvements in these finger characters have close bearing on general appeal and value of hands sent to market. In fact, in high value crops like banana, quality standards have become the most important factor influencing monetary yield and farmers' income. Any management system should aim to produce quality fruits, besides maximizing productivity.

In banana, fruit quality is mainly judged by the sugar content and acidity in the pulp. The foliar SOP sprays appeared to be effective at enhancing various quality parameters such as TSS, reducing, non-reducing and total sugars and acidity (**Table 3**). Venkatarayappa et al. (1979) also obtained better quality parameters with foliar K spray. Higher fruit quality, especially higher sugar content, can be explained by the role K plays in carbohydrate synthesis, breakdown and translocation and synthesis of protein, and neutralization of physiologically important organic acids (Tisdale and Nelson, 1966). Potassium is responsible for energy production in the form of ATP and NADPH in chloroplasts by maintaining balanced electric charges. Besides, K is involved in phloem loading and unloading of sucrose and amino acids, and storage in the form of starch in developing fruits by activating the enzyme starch synthase (Mengel and Kirkby, 1987). The timing of this study's foliar K application also favors the conversion of starch into simple sugars during ripening by activating the sucrose synthase enzyme. In plants well-supplied with K, the osmotic potential of the phloem sap and the volume flow rate are higher than in plants grown under low K fertility, and as a result, sucrose concentration in the phloem sap is increased (Marschner, 1995). Reduced acid content of fruits under low K regimes could be explained by an apparent shunting of phosphoenol pyruvate (PEP) into alternate pathways resulting in a shortage of acetyl CO-A (Pattee and Teel, 1967). Hence, oxaloacetate appeared to be preferentially formed from PEP in plants with low levels of K and this organic acid derivative accumulated. Neutralization of organic acids due to high K level in tissues could have also resulted in a reduction in acidity (Tisdale and Nelson, 1966).

The PLW from harvested fruits, especially under tropical conditions, causes severe economic losses. Several workers have tried nutrient treatments at post-shoot stage to reduce PLW (Swietlik and Faust, 1984). Neypoovan variety receiving foliar spray at either 1.0 or 1.5 % SOP had similar significant reductions in PLW.

This study demonstrated an extension of the fruit ripening period due to foliar SOP spray. The days to edible ripening were fewer in foliar spray treatments—an observation which could be related to the reduced PLW experienced in these treatments. Both the green-life and shelf-life of fruit were significantly lengthened by a maximum of 5.3 and 8.7 days past the control, respectively.

Foliar SOP spray improved final fruit yield and net income (**Table 4**). Steady increases were obtained as spray concentration increased. The 1.5% SOP treatment was most

Table 3. Effect of SOP foliar spray on quality traits and post-harvest life of banana.

Treatment	TSS, %	Reducing sugars, %	Non-reducing sugars, %	Total sugars,%	Acidity, %	Sugar:acid ratio	PLW, %	Green-life, days	Shelf-life, days
Control (Water)	24.4	18.60	1.53	20.35	0.40	50.89	13.24	4.5	6.5
0.5% SOP spray	27.9	19.28	2.15	21.31	0.30	71.04	11.34	4.8	7.8
1.0% SOP spray	27.9	19.57	2.26	21.82	0.26	84.31	10.96	5.2	7.8
1.5% SOP spray	28.9	19.96	2.44	22.36	0.23	97.64	10.34	5.3	8.7
SEd	1.01	0.50	0.048	0.58	0.012	3.29	0.71	0.024	0.48
CD (p=0.05)	2.06	1.02	0.099	1.18	0.024	6.72	1.45	0.048	0.98

Table 4. Economics of SOP foliar spray on banana.

Treatment	Treatment cost, Rs./ha	Total cost, Rs./ha	Total yield, kg/ha	Gross income, Rs./ha	Net income, Rs./ha
Control (Water)	0	90,000	32,400	129,600	39,600
0.5% SOP spray	930	90,930	34,590	138,360	47,430
1.0% SOP spray	1,380	91,380	37,890	151,560	60,180
1.5% SOP spray	1,830	91,830	42,810	171,240	79,410

US$1 = RS.43.95

profitable and doubled net income compared to the control. Yield, quality, and economic traits all suggest significant advantages from foliar spray application during the post-shoot growth stage. It is recommended to integrate similar foliar spray techniques into banana nutrition, besides supplying recommended rates of fertilizers at 3, 5, and 7 months after planting.

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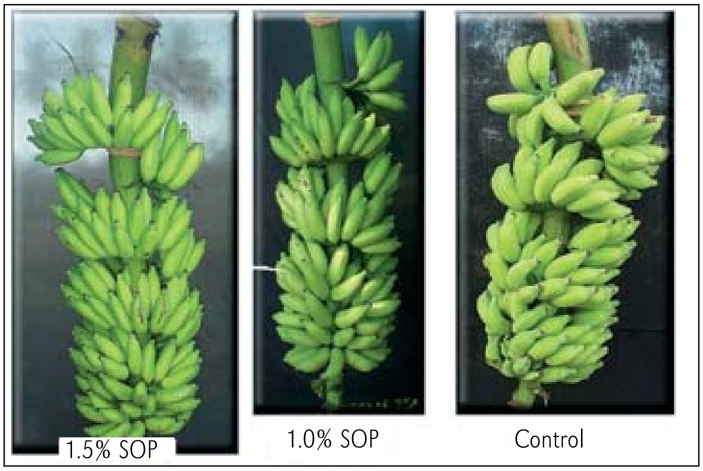

Bunches of banana cultivar Neypoovan from post-shooting spray of nutrients.

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New Posters Feature Forages/ *Southern Forages* Book Now in Fourth Edition

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"The new posters provide one more level of information accessibility for the many people interested in forage grasses and legumes. We have seen the popularity and usefulness of the *Southern Forages* book for many types of audiences and believe the posters will effectively enhance understanding of forage production and management," noted IPNI President Dr. Terry Roberts. Many of the species included on the posters are grown across large areas of North America and some in other countries.

The posters would be appropriate for display in classrooms, seed outlets and farm stores, Extension and soil/water conservation meeting rooms, farm offices, and various other settings. A single poster is available for purchase at US$3.00 plus shipping. The cost for a set including one of each poster is US$8.00 sent folded or US$9.00 rolled in a mailing tube.

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NORTH AMERICA

Long-Term Phosphorus Fertilization Effects on Crop Yields and Soil Phosphorus

By R.E. Karamanos, J.T. Harapiak, and G.A. Kruger

Discontinuing P fertilization after 20 years of annual application of 27 lb P_2O_5/A resulted in significant reduction in barley grain yield, with losses of 21% where P had been applied in the seedrow, 12% where P had been banded with N, and 15% where P had been applied one-third in the seed row and two-thirds banded. While minor benefits to residual soil P were measured from annual application, continued fertilizer P use was required to achieve optimum yields.

Evaluation of the residual effects from P fertilization has been the subject of numerous studies in western Canada (Roberts and Stewart, 1987). Residual P is expected to build in the soil when the removal of P by crops is lower than the fertilizer or manure P applied. However, numerous studies have demonstrated that recovery of P by crops in the year of application is very low (Hedley and McLaughlin, 2005). Fertilizer P recovery remains low and can range from less than 10% up to 30% depending on soil, crop, and management factors (Withers et al., 2005).

However, it has been argued that determining the percentage recovery of P as an estimate of fertilizer P recovery may be inappropriate, and some suggest a budget of inputs and outputs should be developed and related to changes in soil P status (Higgs et al., 2000). Obviously, that latter approach would lead to efficiencies close to 100%, since P losses from soil are minimal.

The objective of this study was to assess the residual effects from 20 annual applications of fertilizer P to a Black Chernozemic soil (Udic Boroll) in Alberta, and measure the impact on succeeding crops that received no fertilizer P. The trial was established in the fall of 1981 at the University of Alberta – Ellerslie Experimental Farm – to assess methods of P placement. The experimental site was divided into two parts. Part A received a blanket application 400 lb P_2O_5/A in the fall of 1981 as triple superphosphate (0-45-0), and Part B received no P fertilizer. A number of treatments were initiated in both parts on an annual basis, including (i) an unfertilized control, (ii) N only treatment that received 72 lb banded N/A, (iii) a treatment that received 72 lb banded N/A and 27 lb seed row-applied P_2O_5/A, (iv) a treatment that received 72 lb broadcast N/A and 27 lb seed row-applied P_2O_5/A, (v) a treatment in which both 72 lb N/A and 27 lb P_2O_5/A were banded (dual banding), and, (vi) a treatment that received 72 lb banded N/A and 27 lb P_2O_5/A split one-third in the seedrow and two-thirds in the band. Banded N and P (at a depth of 5 in.) and broadcast and incorporated N fertilizer treatments were applied in the fall of the previous year; seedrow-placed P was applied at seeding time. Phosphorus in all treatments was applied as triple superphosphate (0-45-0), whereas N was in urea (46-0-0) form. Fertilization in all treatments of both parts of the study was discontinued in the fall of 2001 and the experiment was terminated after the 2004 growing season. Barley was grown in all except one year (1995, canola). Commencing in 2002, only treatment (vi) was fertilized with P at a rate of 27 lb P_2O_5/A, however seedrow-applied. All treatments other than the control still received 72 lb banded N/A according to the original schedule. Composite soil samples from 0 to 6 in. depth of the control treatments were collected on an annual basis either in the fall after harvest and/or spring prior to sowing each year. Soil samples were analyzed for "available" P using the bicarbonate (Olsen et al., 1954) method.

Detailed sampling of all plots of Part B and treatment (vi) of Part A (the one receiving 27 lb P_2O_5/A in 2002-2004) was carried out in the fall of 2005 after a chemical fallow year. Samples were taken from 0 to 4 in. and 4 to 8 in. depth along a 16.4-foot transect crossing two rows in each plot. The transect was drawn at an angle, so that when projected on a line vertical to the direction of the seeding rows, the distance between sampling points was 1 in. Fourteen such sampling points were duplicated in each plot and the two corresponding sub-samples for each point were composited into one, thus resulting in 14 samples per plot per sampling depth. All sub-samples were analyzed for "available" P using the bicarbonate method (Olsen et al., 1954). In the summer of 2006, PRS™ probes (Hangs et al., 2004) were inserted on the row and in the middle of the inter row spaces of the same plots where soil samples were taken in the previous fall. Four anion PRS™ probes were buried per plot at each of two depths (0 to 4 in. and 4 to 8 in.). After 28 days, the PRS™ probes from each plot depth and treatment were retrieved, washed with deionized water, and analyzed for P as described by Hangs et al., 2004.

After the first 10 years of growing barley on both sites, no difference in the yields was observed between the two parts of the study where one part received the residual P fertilizer. However, the residual effects from the original 400 lb P_2O_5/A had been exhausted after 10 years of barley production (**Figure 1**). This is corroborated by comparing the grain yields and soil test levels of the control treatments of Parts A and B.

A number of techniques have been utilized to assess fertilizer P use efficiency (FPUE). Most commonly, FPUE is estimated by comparing uptake of P by plants grown in a fertilized soil to that of an unfertilized control, also known as 'apparent recovery'. Total uptake of P during the first 20 years of the experiment ranged from 682 to 736 lb P_2O_5/A for the P treatments compared to 568 lb P_2O_5/A for the treatment that had received N only. Hence, net uptake (uptake in any P treatment-uptake in control) ranged from 114 to 168 lb P_2O_5/A (**Figure 2**). Since a total of 532 lb P_2O_5/A was applied, it resulted in an apparent P recovery (FPUE) of between 21.2 and 31.4% for the 20-year period from 1982 to 2001. The lowest recovery rate was obtained when N was broadcast and incorporated and P was seedrow-placed. This reflects the lower fertilizer N use efficiency (FNUE), as it has been already

Abbreviations and notes for this article: P = phosphorus; N = nitrogen; ppm = parts per million; PRS = Plant Root Simulator

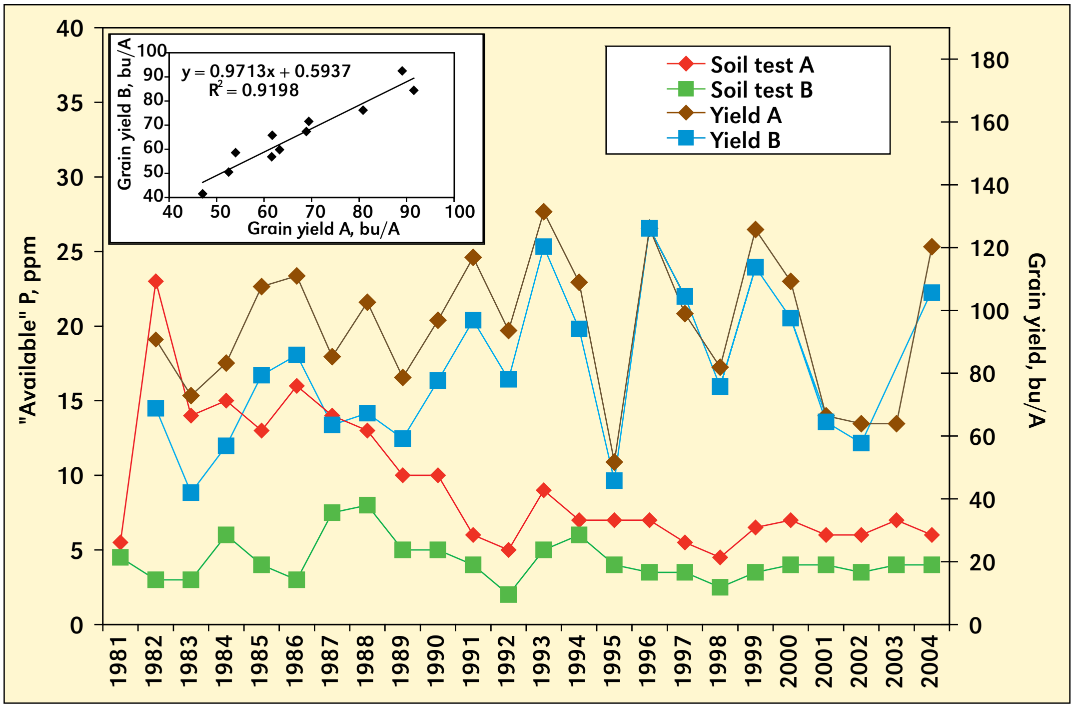

Figure 1. Comparison of barley grain yields between control treatments of Parts A and B from 1982 to 2001 (enclosed regression between 1993 and 2001 excludes canola in 1995).

demonstrated that N fertilization results in increased P uptake and, consequently, higher P recovery in crops (Halvorson and Black, 1985). In spite of this, interruption of P fertilization in 2002 led to significant yield decreases with average losses over a 3-year period (2002-2004), being greater (21%) when 27 lb P_2O_5/A was being seed-placed for the first 20 years, and lesser with one-third seed-placed and two-thirds banded (15%) and banded with N (12%) (**Figure 3**).

Soil P levels showed virtually no differences between "available" P levels on the row (where P placed) and in the inter-row spaces (**Table 1**). The exception was at the 4 to 8 in. depth of N+P banded treatment, in which P levels on the row were 2 ppm greater than in the inter-row spaces, reflecting accumulation of fertilizer P at that depth. Lack of differences in the remaining treatments would appear logical, since the surface soil layer above the depth of banding was being disturbed and redistributed every year prior to seeding. Further, there was a difference of up to 4 ppm on the row, and 3 ppm in the inter-row spaces, of the 0 to 4 in. layer between the P fertilized treatments and the unfertilized controls (**Table 1**). These "available" P levels in the 0 to 4 in. layer are considered very low (McKenzie et al., 2003; Saskatchewan Agriculture and Food, 2006) to low (Manitoba Agriculture, Food and Rural Initiatives, 2001). Hence, a greater than 75% probability of response to P based on the above sources should be anticipated. However, differences in the extractable P levels of previously P-fertilized treatments were not sufficiently wide to fully explain the observed yield losses.

Four-week (28 day) burial of PRS™ probes in 2006 measured major differences in supply rates, hence P availability, based on management and P placement practices. The supply rates and bicarbonate extractable P levels of the N banded P seed-placed and N+P banded treatments are contrasted in **Figure 4**. Although distribution of bicarbonate-extractable P in the seed-placed P treatment was fairly equal over the 14 sampling points, supply rates were distinctly different between on-row and inter-row spaces (**Figure 4a**). Supply rates on the row averaged 3.3 µg/10 cm^2/28 days and those in the inter-row spaces were 24% greater at 4.1 µg/10 cm^2/28 days. Hence, in this treatment, PRS™ probes were able to isolate the depletion of P reserves on the row, since the position of the row remained fairly stable over the experiment, and the inability of the roots to reach the P reserves that were stored in the middle of the inter row spaces. Conversely, supply rates in the banded

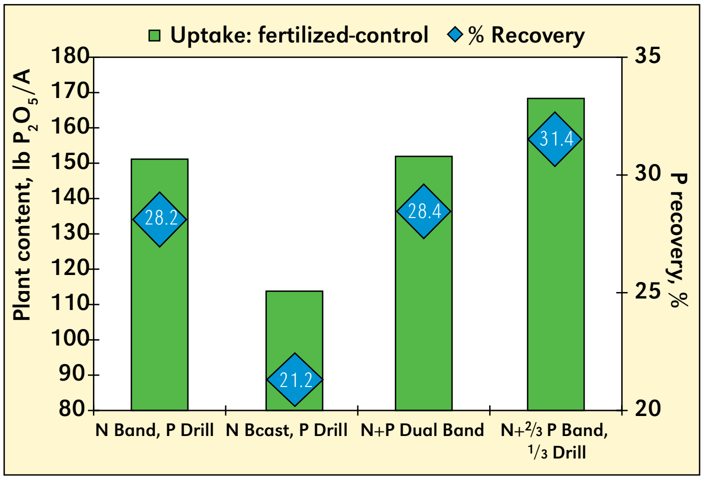

Figure 2. Total net uptake and 'apparent' P recovery after 20 annual applications of 27 lb P_2O_5/A in the form of triple superphosphate (0-45-0).

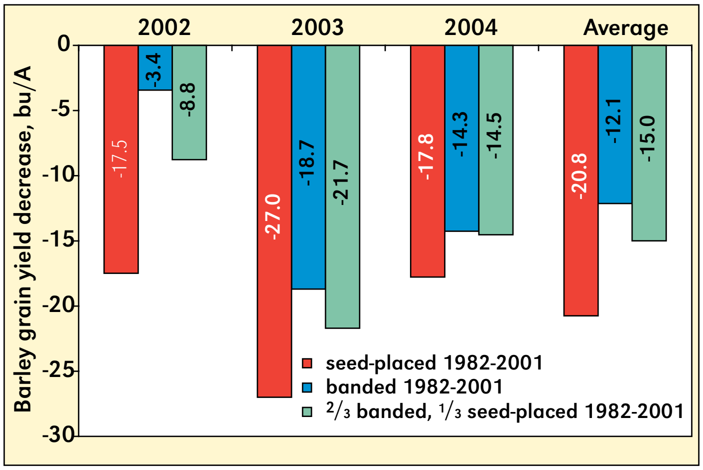

Figure 3. Barley grain yield loss resulting from discontinuing P application after 20 years of annual application of 27 lb P_2O_5/A as 0-45-0.

Table 1. Basic statistics for detailed sampling of two rows of every plot of Part B in 2005.

	Depth, in	Min.	Max.	Mean	On row, A	Between rows, B	Delta A-B
		lb/A					
No fertilizer	0-4	9.1	10.7	10.0	9.6	10.0	-0.4
	4-8	5.4	7.3	6.4	6.2	6.5	-0.4
N banded, no P	0-4	9.3	11.3	10.2	9.9	10.3	-0.4
	4-8	5.0	7.3	6.3	5.4	6.3	-0.9
N banded, P seed-placed	0-4	10.4	12.5	11.4	11.6	11.4	0.2
	4-8	6.2	8.1	6.8	6.4	6.9	-0.4
N B&I[1], P seed-placed	0-4	11.1	13.1	12.1	12.3	12.1	0.3
	4-8	5.4	7.1	6.2	5.9	6.2	-0.4
N+P banded	0-4	11.5	14.5	12.8	13.7	12.6	1.1
	4-8	6.8	10.9	8.3	10.0	8.0	2.0
N+⅔ P banded+ ⅓ P seed-placed	0-4	10.1	13.5	11.4	11.1	11.4	-0.4
	4-8	5.5	7.1	6.5	6.4	6.5	0

[1] Broadcast and incorporated.

treatments were significantly higher on the row (4.2 µg/10 cm^2/28 days) compared to the middle of the inter-row spaces (3.3 µg/10 cm^2/28 days) and reflected both higher accumulation of P in the band as well as possible translocation to shallower depths via biocycling (**Figure 4b**). Supply rates greater than 3.5 µg/10 cm^2/28 days are considered as an indicator of sufficient P supply in the soil (Hangs et al., 2002).

Barley grain yields obtained in the last year of the study were significantly correlated with supply rates for on row (r^2 = 0.936), in the middle of the row spaces (r^2 = 0.678) and when supply rates were combined into one per plot (r^2 = 0.891) (data not shown). Corresponding correlations of barley yields with bicarbonate extractable-P levels were also statistically significant, but lower (0.685, 0.670, and 0.684). Similar trends were obtained when the average 23-year yields were correlated with supply rates and bicarbonate extractable-P levels (data not shown).

Residual P from long-term P fertilization was not sufficient alone to provide all the P requirements of barley grown in a monoculture system when P fertilization was discontinued after 20 years of application. PRS™ probes afford a satisfactory means of identifying point sources, as well as long-term trends of P fertilization, i.e., placement and long-term fertilization effects. The use of PRS™ probes allowed us to interpret 93% of variations in P removal by barley over the duration of the experiment.

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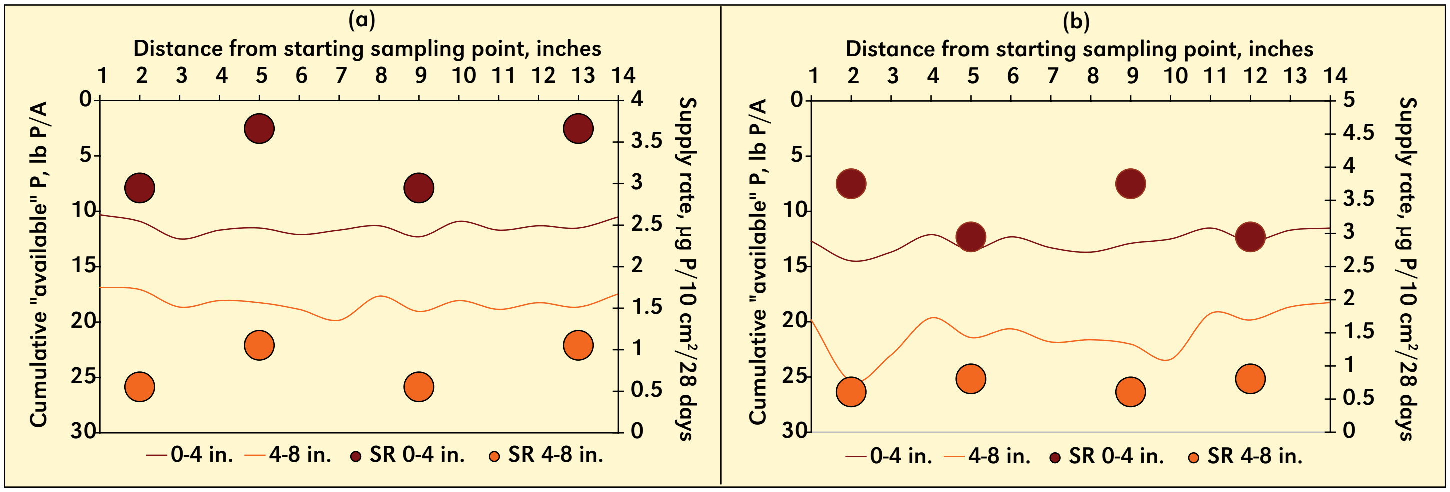

Figure 4. Distribution of bicarbonate extractable-P and P supply rates in the 72 lb banded N/A and 27 lb seedrow-applied (SR) P_2O_5/A (a) and both 72 lb N/A and 30 lb P_2O_5/A banded (dual banding) (b) treatments.

Full-Season, Irrigated Soybean Response to Potassium Fertilization in Arkansas

By Nathan A. Slaton, Russell DeLong, Bobby R. Golden, and Morteza Mozaffari

Soil test correlation and fertilizer rate calibration studies in Arkansas showed that soil test K is an excellent means of characterizing the need for K fertilization of soybeans on silt loam soils in eastern Arkansas. Significant yield increases with K fertilization occurred at 10 of 19 harvested sites, with soil test K ranging from 46 to 167 ppm. Tissue analyses results indicate 1.8% K may be needed in soybean leaves to achieve 90% of maximum yield.

About 60% of the 3 million acres of soybeans [*Glycine max* (Merr.) L.] grown annually in Arkansas receive irrigation. Many of the soybeans are rotated with rice (*Oryza sativa* L.) and sometimes double-cropped following winter wheat (*Triticum aestivum* L.). The soils have low (sandy and silt loams) to high (clayey) cation exchange capacities. Many of the silt loams have shallow topsoil, low organic matter (1.0 to 2.5%), and a hardpan (3 to 6 in. deep) which restricts water infiltration and rooting depth.

These soil characteristics are ideal for flood-irrigated rice production, but offer significant challenges for upland crops grown in rotation. Despite these challenges, these soils can produce good soybean yields, with a high level of management.

Existing P and K fertilizer recommendations developed in the 1980s for soybean have been questioned because of higher soybean yield potential, crop rotation changes, and increased fertilizer costs. Field observations and analysis of soybean tissues submitted for nutrient analysis indicate that K deficiency is becoming more common in Arkansas.

Tissue analyses results indicate 1.8% K may be needed in soybean leaves to achieve 90% of maximum yield.

The objective of the research reported here was to evaluate full-season, irrigated (as needed or feasible) Group IV (five sites) or V (16 sites) soybean cultivar response to K fertilization on silt loam soils. Before K fertilizer treatments were applied (March to May) a composite soil sample was collected from the 0 to 4 in. depth from each replicate of each study to characterize initial soil properties (**Table 1**). Five rates (up to 150-160 lb K$_2$O/A) of muriate of potash were broadcast to the soil surface shortly before or after planting. Triple superphosphate (~60 lb P$_2$O$_5$/A) was applied to ensure that P was not yield limiting and granular boron (B) fertilizer (1.0 lb B/A) was also applied to most, but not all, fields. Each trial was a randomized complete block design with 6 to 8 replications. Recently matured trifoliate leaves (20)

Table 1. Selected soil and agronomic information from 21 K fertilization trials conducted in Arkansas since 2004 on silt loam soils.

			Unfertilized control data			Yield
Soil series	Soil pH	Mehlich 3 soil test K, mg/kg	Actual yield, bu/A	Relative yield, as % of maximum with K, %	Tissue K, %	Significance compared to K treatments, p-value
Bonn-Foley	7.6	46	26	59	0.80	0.0016
Calhoun	7.1	65	42	70	1.42	<0.0001
Calhoun	7.6	71	40	76	1.55	0.0003
Hillemann	8.2	72	43	77	1.68	0.0008
Calhoun	7.8	73	46	70	1.27	0.0197
Calhoun	7.9	85	45	78	–	0.0045
Hillemann	8.2	86	49	74	1.27	<0.0001
Calhoun	7.9	96	47	78	1.24	0.0002
Henry	7.6	98	37	97	–	0.5558
Henry	6.2	101	73	90	1.53	0.4139
Calhoun	7.9	102	55	88	1.58	0.0244
Henry	6.8	103	29	88	1.68	0.1960
Calhoun	7.9	103	50	81	1.53	<0.0001
Calloway	7.8	104	53	93	1.75	0.1041
Henry	7.9	108	–	–	1.89	–
Dewitt	7.4	110	44	92	1.66	0.8618
Hillemann	6.5	117	–	–	1.71	–
Dewitt	5.4	125	30	97	1.94	0.3607
Dewitt	5.3	154	77	97	1.71	0.4072
Calloway	7.2	154	51	96	2.18	0.9108
Calhoun	7.5	167	64	94	2.14	0.5215

Abbreviations and notes for this article: K = potassium; P = phosphorus; ppm = parts per million;

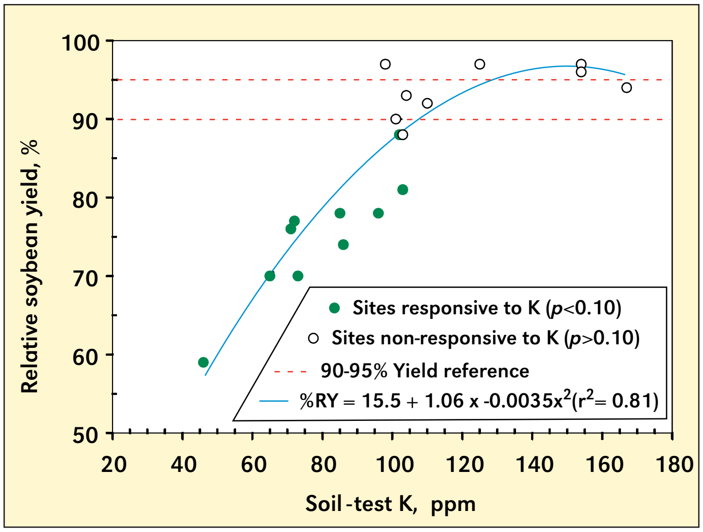

Figure 1. Relationship between soil test K (0 to 4 inches) and relative yield of soybean grown on silt loam soils in Arkansas.

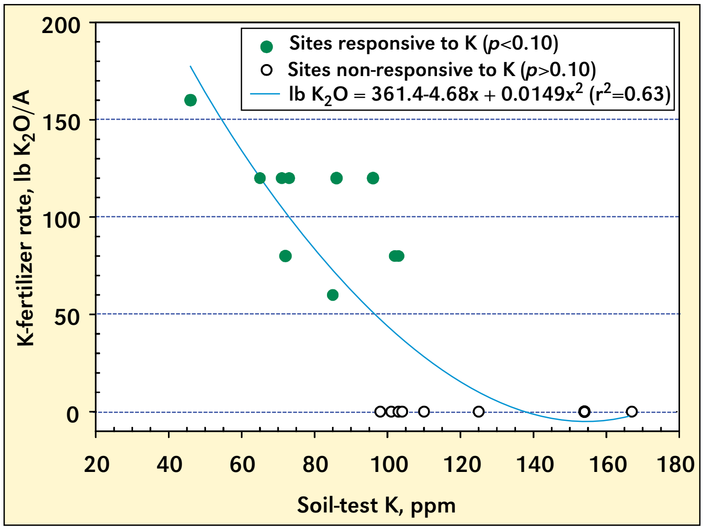

Figure 2. Relationship between soil test K and K_2O rate (lb/A) needed to produce 95% relative yield of soybean grown on silt loam soils in Arkansas.

were collected from each plot at the R1-R2 growth stage and analyzed for nutrient concentrations. The middle of each plot was harvested with a plot combine at maturity and actual yields were converted to percent relative yield, by dividing the unfertilized control yield by the highest yielding treatment receiving K fertilizer at each site, multiplied by 100.

Significant ($p<0.10$) yield increases from K fertilization occurred at 10 of the 19 harvested sites (**Table 1**). All sites showing positive and significant yield increases to K fertilization had 0 to 4 in. soil test K <110 ppm. Only four harvested sites had soil test K >110 ppm, none of which showed significant yield increases to K fertilization. Sypmtoms of K deficiency were observed on about half of the responsive sites, which may suggest that growers have been unaware of hidden K hunger.

The analyses showed that 81% of the variability in soybean yield was explained by soil test K (**Figure 1**). Soils with soil test K from 111 to 137 ppm produced 90 to 95% of soybean maximum yield potential without K fertilization. Based on this estimate of a critical soil test K, over 50% of the soil samples submitted for soybean production in Arkansas require K fertilization to reach maximum yield potential.

Potassium fertilization produced significant yield increases at 7 of 7 sites with soil test K <91 ppm (Low or Very Low soil test K), at 33% (3 of 9 sites) of the fields with soil test K of 91 to 130 ppm (Medium), and 0% (0 of 3 sites) of the fields with soil test K >130 ppm (Optimum). The average K rates needed to produce near maximum yields averaged 160, 87, 31, and 0 lb K_2O/A for soils having Very Low, Low, Medium, and Optimum soil test K levels, respectively. Soybean did not respond to K fertilization consistently when soil test K ranged from about 95 to 110 ppm (**Figure 1**).

The K_2O rates needed to produce 95% relative yield were estimated by regressing the K fertilizer rate that produced 95% relative yield against soil test K. For sites with no significant yield differences among K rates, the K rate needed to produce 95% relative yield was entered as 0 lb K_2O/A. The rate of K needed to maximize soybean yields increased rapidly as soil test K declined (**Figure 2**), but was nominal as the soil test K approached 100 ppm.

The profitability of K fertilization was calculated using the estimated benefits of K fertilization (**Figure 1**) with the predicted K rates (**Figure 2**) needed to maximize soybean yields, with reasonable price estimates for muriate of potash and soybean (**Table 2**). The economic benefits of K

Table 2. Estimated yield potential, K fertilizer rates, and net returns from K fertilization of soybean in Arkansas.

	Predicted information					
Mehlich 3 soil test K, ppm	Relative yield[1] %	Actual yield[1] bu/A	K_2O rate[2], lb K_2O/A	Fertilizer cost[3], $/A	Net returns from K fertilization @ $6.00/bu soybean[4], $/A	Net returns from K fertilization @ $7.50/bu soybean, $/A
50	60	32	164	$36.90	$71.10	$98.10
60	67	35	134	$30.15	$59.85	$82.35
70	73	38	107	$24.08	$47.93	$65.92
80	78	41	82	$18.45	$35.55	$49.05
90	83	43	61	$13.73	$28.28	$38.77
100	87	45	42	$9.45	$20.55	$28.05
110	92	47	27	$6.08	$11.93	$16.42
120	94	48	14	$3.15	$8.85	$11.85
130	94	49	5	$1.13	$4.88	$6.37
140	95	50	0	$0.00	$0.00	$0.00

[1] Predicted relative (Figure 1) and actual yields when no K fertilizer is applied. Predicted actual yield assumes a maximum yield potential of 50 bu/A when soil test K is >140 ppm.

[2] Predicted rate of K_2O fertilizer/A to maximize soybean yields.

[3] Estimated K_2O fertilizer costs assuming $0.225 per pound of K_2O.

[4] Estimated net return above K_2O fertilizer rate when the recommended K_2O rate is applied.

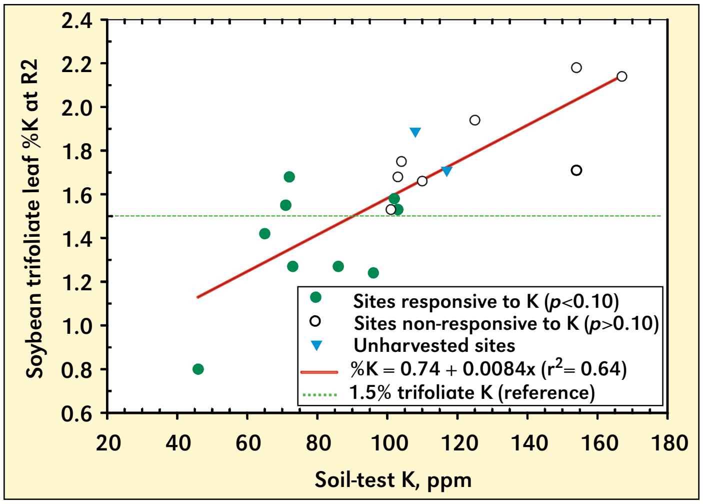

Figure 3. Relationship between soil test K (0 to 4 in.) and trifoliate leaf K concentration at R2 stage of soybean grown on silt loam soils in Arkansas.

fertilization are clear when soil test K is <90 to 100 ppm. When soil-test K was >90 to 100 ppm, the frequency of significant yield increases from K fertilization was less certain, and application of K rates greater than those predicted for maintaining near maximum yields may be desired to simply replace K removed in harvested grain to sustain soil productivity.

Potassium concentration of recently matured trifoliate leaves at the R2 stage increased linearly as soil test K increased (**Figure 3**, r^2 = 0.64, n = 19). Tissue K concentrations at R2 were also excellent predictors of relative yield response to K fertilization (**Figure 4**). These data clearly indicate that unfertilized soybean with <1.5% K at R2 respond positively to K fertilization, but the critical K concentration at R2 for irrigated soybean grown on silt loam soils in Arkansas may be >1.5%, in contrast with much of the published literature. Our data indicate about 1.8% tissue K to achieve 90% relative yield. Significant yield increases from K fertilization occurred at 4 of 9 sites with tissue K concentrations between 1.5 and 1.8%. Two other sites with tissue K <1.8% showed non-significant trends for positive yield responses to K fertilization. Trifoliate leaf K concentrations <1.5% K at initial pod set are clearly deficient and concentrations ranging from 1.5 to 1.8% should likely be categorized as Low.

Young soybeans showing K deficiency symptoms.

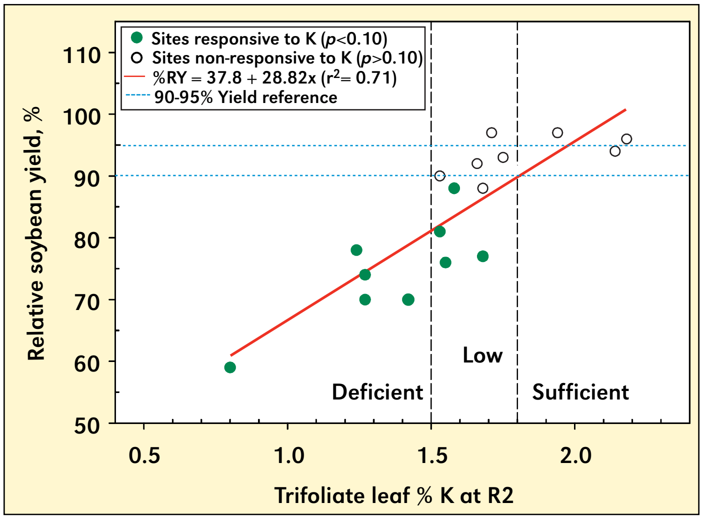

Figure 4. Relationship between trifoliate leaf K concentration at R2 stage and relative yield of soybean grown on silt loam soils in Arkansas.

Summary

Fertilizer recommendations for irrigated soybean in Arkansas were changed in 2006 to reflect the need for greater K fertilizer rates on soybean grown on sandy loam to silt loam soils with 'Medium' or 'Low' soil test K levels. Mehlich 3 soil test levels of Very Low (<61 ppm), Low (61 to 90 ppm), Medium (91 to 130 ppm), Optimum (131 to 175 ppm), and Above Optimum (>175 ppm) were established with associated recommended K fertilizer rates of 160, 120, 60, 50, and 0 lb K_2O/A, respectively. The recommended K rates are aimed at producing near maximal soybean yields while building and maintaining soil test K in the Medium soil test level. Recommendations may be refined in future years as additional data are collected.

An ongoing K study in Arkansas suggests that 60 lb K_2O/A/yr, which approximates crop K removal during a 2-year rice-soybean rotation cycle, has maintained the initial soil test K after four rice and three soybean crops with average yields of 163 bu/A for rice and 44 bu/A for soybean. Annual applications of K rates >60 lb K_2O/A/yr have increased soil test K by 1 ppm for each 4 lb K_2O/A/yr, and in some years have produced greater crop yields than 60 lb K_2O/A/yr. Arkansas soybean growers have been encouraged to use these K recommendations as a general guideline and to make adjustments when individual field history indicates higher yields and greater annual K removal rates.

IPNI/FAR Project # AR-30F

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For further reading

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Thomas L. Jensen Joins Staff of IPNI as Northern Great Plains Director


Dr. Tom Jensen

Dr. Thomas L. Jensen is joining the staff of IPNI as Northern Great Plains Regional Director effective May 1. He will be based in the Saskatoon, Saskatchewan, office of the Institute, with responsibility for agronomic programs of the organization in the provinces of Alberta, Manitoba, and Saskatchewan, plus the states of Montana and North Dakota.

"We are very happy to have Tom Jensen joining in the important work of this new organization," said IPNI President Dr. Terry L. Roberts. "He has an outstanding background that bridges academic, industry, and farm-level expertise in crops, soils, environment, and related issues. Dr. Jensen is well-qualified to direct the work of the Institute in this key region."

Dr. Adrian M. Johnston, who has served as Director of the Northern Great Plains Region for the past several years, was recently promoted to Vice President, Asia Group, and has responsibility for IPNI programs in China, India, and Southeast Asia. He is also based in Saskatoon.

A native of southern Alberta, Dr. Jensen received his B.Sc. in 1979, his M.Sc. in 1985, and his Ph.D. in 1996, all at the University of Alberta. His Ph.D. thesis examined the effect of three tillage systems on the growth of cultivars of canola, barley, and field pea. From 1979 until 1982 he was a research agronomist in the Soil Science Section of Agriculture and Agri-Food Canada. He worked for Alberta Agriculture and Food from 1982 through 1995 out of Lethbridge and later Edmonton, primarily in soil conservation, specializing in conservation tillage research and extension. From 1995 to 2003, Dr. Jensen was Corporate Agronomist for Agrium Inc. in Calgary. Since April 2003, he has been employed with Agricore United, based in Calgary, most recently with the title of Agronomic Research and Development Manager.

Throughout his career, Dr. Jensen has been active in community and professional organizations, including recent service as a representative on the Nutrients in the Environment Committee of the Canadian Fertilizer Institute. He is a Certified Crop Adviser and a member of the American Society of Agronomy, Soil Science Society of America, and Alberta Institute of Agrologists.

Dr. Jensen can be contacted by e-mail at: tjensen@ipni.net

Conversion Factors for U.S. System and Metric Units

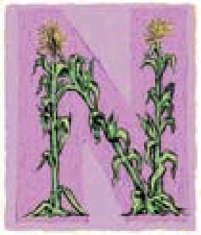
Because of the diverse readership of *Better Crops with Plant Food*, units of measure are given in U.S. system standards in some articles and in metric units in others…depending on the method commonly used in the region where the information originates. For example, an article reporting on corn yields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

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

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

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

Will Biotechology Replace Nitrogen Fertilizer?



Research in molecular biology has put highly desirable and widely adopted traits for herbicide and pest resistance into crop plants. It is expected that the science will soon impact the rate of progress in yield improvement, and that genetically modified plants may show increased stress tolerance and nutrient use efficiency. What is the likelihood of being able to replace N fertilizer altogether?

Plants of the legume family have always been able to make their own N. A complex symbiosis with rhizobial bacteria lets them make the ammonium they need for protein synthesis directly from the N gas abundant in the air. They fix N using the nitrogenase enzyme of the bacteria. It costs the plant something for energy, but perennial species like alfalfa are efficient enough at it that they rarely respond to N fertilizer. Transferring the trait to non-legume crops would be a major challenge. The most important grain crops of the world—the cereals…corn, wheat, and rice—are all non-legumes. They take most, if not all, of their N from the soil. They generally do not produce high yields without N fertilizer.

Research on the genetic control of the legume symbiosis has led to identification of the plant genes that trigger the formation of nodules. A breakthrough was reported in the summer of 2006. Dr. Giles Oldroyd, a scientist working at the John Innes Centre (JIC) in Britain, said: “The fact that we can induce the formation of nodules in the plant in the absence of the bacteria is an important first step in transferring this process to non-legumes…. However, we still have a lot of work before we can generate nodulation in non-legumes.”

Considering that both the plant and the bacteria need to take many more steps after nodulation in order to begin the process of effectively taking N from the air, it is clear that the science behind the transfer of the process to non-legumes is in its infancy. The genome (DNA sequence) of the rhizobial bacteria that fix N in alfalfa was published in 2001. At least 100 scientific studies since then have cited the article—which shows that research is active. However, owing to the complexity of the processes involved, much remains to be discovered.

The Brazilian Agricultural Research Corporation announced in December 2006 that it has finished mapping and sequencing the genome of another bacterium that works as a natural fertilizer. *Gluconacetobacter diazotrophicus* is found in sugarcane, sweet potatoes, and pineapples. As an endophyte—living between the cells of the roots of its host—its association is not as intimate as that of the rhizobia that invade the root cells of a legume to form nodules. However, this organism is responsible for the low N requirements of sugarcane and contributes to the high energy efficiency of the Brazilian ethanol industry.

Genetic improvement has contributed to steady yield gains in North American corn production. Since 1940, yields have been on an increasing trend, growing by about 1.8 bu/A each year. Some anticipate that genetic engineering will almost double the rate of yield improvement. The past increase in yields has been accompanied by improved N use efficiency. Biotechnology is reducing the amount of N fertilizer used to grow a bushel of corn, because yields are increasing faster than rates applied.

Sunlight, water, and nutrients remain the major factors limiting crop yields. Biotechnology has potential to improve the efficiency by which plants utilize all three. But growing global demand for food, fuel, fiber, and feed ensures that plant nutrient inputs will continue to play an important role for the foreseeable future.

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