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BETTER CROPS WITH PLANT FOOD

Vol. LXXXIX (89) 2005, No. 1

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Cover Design: Todd Scott/Kathy Heiner

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

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

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W.J. Doyle Elected Chairman, F.W. Corrigan Vice Chairman of PPI Board

William J. Doyle, President and Chief Executive Officer (CEO) of Potash Corporation of Saskatchewan Inc. (PotashCorp), was elected Chairman of the Potash & Phosphate Institute (PPI) Board of Directors at a recent meeting. **Fredric W. "Fritz" Corrigan**, CEO and President of Mosaic, was elected Vice Chairman of the PPI Board.

"The extensive achievement, experience, and leadership of these individuals is welcomed by the Institute as they serve in these key positions," said Dr. David W. Dibb, PPI President.


W.J. Doyle

Mr. Doyle was appointed CEO of PotashCorp in July 1999 after 12 years as a key member of the company's management team. PotashCorp is the world's largest integrated producer of nitrogen, phosphate, and potash. Mr. Doyle joined the company as President of PCS Sales in 1987, assuming responsibility for the sales and distribution of all potash produced by the company. In March 1995, he was appointed Executive Vice President of PotashCorp, where he took charge of all sales for the company—including phosphate and nitrogen—following a series of acquisitions. In July 1998, he was named President and Chief Operating Officer.

Mr. Doyle serves on the boards of Canpotex Limited and The Fertilizer Institute (TFI). He is Chairman of the Production and International Trade Committee for the International Fertilizer Industry Association (IFA). He will also serve as chairman of the Foundation for Agronomic Research (FAR) Board of Directors.


F.W. Corrigan

Mr. Corrigan most recently served as Executive Vice President of Cargill, Incorporated. He was Chairman of the Board of Cargill Fertilizer, Inc., Chairman of the Cargill Corporate Business Excellence Committee, and a member of Cargill's Corporate Leadership Team and Corporate Public Affairs Committee. (Mosaic was recently formed by the combination of IMC Global with Cargill Incorporated's crop nutrition businesses.)

After joining Cargill in 1966, Mr. Corrigan held various positions, including President of Cargill's Fertilizer Division, Cargill Worldwide Fertilizer, and Cargill's Agriculture-Biosciences Group. Mr. Corrigan serves on the Board of Directors of the Florida Phosphate Council and is former Board Chairman. He also serves on the Board of Directors and is former Board Chairman of TFI.

In other action of the PPI Board, William J. Whitacre was elected Chairman of the Finance Committee. Mr. Whitacre is President, AgriBusiness Group, J.R. Simplot Company. BC

PPI/PPIC on the Web: www.ppi-ppic.org

Learn more about PPI/PPIC programs, research support, and links by visiting the website: >**www.ppi-ppic.org**<. From the central website, visitors may reach the various individual regional sites where PPI/PPIC programs are at work. BC

Terry L. Roberts Named Senior Vice President as Mark D. Stauffer Retires from PPI/PPIC

Dr. Terry L. Roberts has been promoted to Senior Vice President of PPI/PPIC effective November 1, 2004 and International Program Coordinator of the organization effective January 1, 2005.

Dr. Mark D. Stauffer of Saskatoon, Saskatchewan, who served as PPI Senior Vice President, International Program Coordinator, and President of PPIC since 1994, retired at the end of 2004.

"In this action, the PPI Board of Directors expressed its great appreciation to Dr. Stauffer for his dedicated performance over the past 17 years with PPI/PPIC," said Dr. David W. Dibb, President of PPI. "Dr. Roberts has several years of experience in our international programs and will transition quickly to these broader responsibilities. He will continue his leadership role in Communications and Member Services as well."


T.L. Roberts

Dr. Roberts joined the staff of PPI/PPIC in 1989 as Western Canada Director. In 1999, he moved to PPI headquarters in Norcross, Georgia. In addition to his responsibility for Communications and Member Services, Dr. Roberts has been PPIC Vice President for Latin American Programs and served as President and now Vice President of the Foundation for Agronomic Research (FAR). A native of southern Alberta, he grew up in a family owned and operated retail fertilizer business. He received a B.S.A. in Crop Science (1981) and a Ph.D. in Soil Fertility and Plant Nutrition (1985) from the University of Saskatchewan. Dr. Roberts is a Fellow in the American Society of Agronomy (ASA)

Dr. Stauffer joined the PPI/PPIC staff in 1988 as Western Canada Director, then moved in 1989 to Ontario to serve as Director for Eastern Canada, Michigan, and Ohio. In 1994, he became PPI Vice President and then Senior Vice President for International Programs and President of PPIC. A native of Ontario, Dr. Stauffer took his undergraduate training at the University of Guelph and earned his Doctorate in Agronomy at Virginia Polytechnic Institute and State University. He worked in agricultural research, sales, and management in the U.S. and Canada and was a research scientist with a major agricultural chemical company in Saskatchewan before joining PPI/PPIC. Dr. Stauffer has actively served in many community and professional organizations, including ASA and the Canadian Society of Agronomy. BC


M.D. Stauffer

PPI/PPIC Staff Honored in Latin America

Directors of two PPI/PPIC programs were recently recognized for distinguished activities in agronomic research and education in Latin America. PPI/PPIC-IPI Brazil (POTAFOS) Director Dr. T. Yamada and PPI/PPIC Northern Latin America Program (INPOFOS) Director Dr. José Espinosa, were honored at the closing ceremony of the XVI Latin American Soil Science Congress and XII Colombian Congress of Soil Science in Cartagena, Colombia. BC

T E X A S

Fertilization for Cotton-Sorghum Rotations vs. Continuous Cotton

By J.D. Booker, K.F. Bronson, W.J. Keeling, and C.L. Trostle

Sorghum is the main rotation crop in the 3 million acre cotton growing region of the Southern High Plains of Texas. However, fertilizer requirements for the cotton-sorghum rotation are not well documented. We observed no rotation effect on the yield of cotton. Nitrogen (N) and phosphorus (P) fertilizer response was affected by rotation during the 4 years of this study.

Crop rotation has been long recognized as a benefit to soil and crops from the standpoint of pest, diseases, and soil fertility. The main rotation crop in cotton cropping in the Southern High Plains is sorghum. Surprisingly, yield data on the cotton-sorghum rotation compared to continuous cotton for this region is sparse. In other regions, rotating sorghum with cotton has reportably helped control nematodes in cotton. Although much soil fertility information has been generated in the last 40 years on mono-cropped sorghum and cotton, very little study has been done on the fertilizer needs of the cotton-sorghum rotation.

In the 2000 cropping season, we established a limited irrigation study evaluating rotation sequences of cotton-sorghum, sorghum-cotton, and continuous cotton. Fertilizer treatments included three rates of N, two rates of P, and two rates of zinc (Zn). The main objective of this study was to document N, P, and Zn fertilizer response for the cotton-sorghum and cotton-cotton rotations. We also tested the hypothesis of yield gains by rotating versus mono-cropping. We compared soil organic matter build-up by rotating with sorghum compared to continuous cotton.

This field research study, located at the Texas A&M University Lubbock Research & Extension Center, was in a split-plot design with three replicates. Main plots (eight 40-in. rows wide, by 200 ft. long) were crop rotation: continuous cotton, cotton-sorghum, and sorghum-cotton. Subplots (eight 40-in. rows wide, by 50 ft. long) were factorial combinations of three rates of N, two rates of P, and two rates of Zn fertilizer. Crops were planted in early May on 40-in. wide ridges that were re-listed every spring following fall disc plowing. Soil samples were taken every spring from the 0 to 6, 6 to 12, 12 to 24, and 24 to 36 in. soil layers for extractable soil nitrate (NO_3^-). The 0 to 6 in. depth was analyzed for other nutrients such as P, potassium (K), Zn, and iron (Fe). Additionally, we analyzed the top two layers for soil organic matter by "loss on ignition" and for total soil carbon (C) and N by dry combustion.

Table 1 describes the soil test results and the rates of fertilizer applied. Phosphorus (0-18-0 as H_3PO_4 in 2000 and in 2001, 10-34-0 in 2002 and 2003), and Zn (10% EDTA-Zn) were applied pre-plant by knifing-in liquid fertilizers 3 in. deep

Cotton and sorghum plots in Texas study.

Table 1. Soil test results (fertilized plots after 2000) and N, P, and Zn fertilizer rates applied to cotton following cotton, cotton following sorghum, and sorghum following cotton.

Crop	Previous crop	Soil NO_3-N	1st N rate	2nd (2x) N rate	Soil P ppm	P rate lb P_2O_5/A	Soil Zn, ppm	Zn rate lb Zn/A
		lb/A						
				Spring 2000				
Cotton	N/A	39	51	102	20	45	0.25	2
Sorghum	N/A	39	31	62	20	40	0.25	4
				Spring 2001				
Cotton	Cotton	99	0	0	35	0	0.33	2
Cotton	Sorghum	22	68	136	27	30	0.36	0
Sorghum	Cotton	75	0	0	28	20	0.45	0
				Spring 2002				
Cotton	Cotton	52	38	76	39	0	0.32	0
Cotton	Sorghum	20	70	140	29	30	1.4	0
Sorghum	Cotton	54	16	32	30	20	0.41	2
				Spring 2003				
Cotton	Cotton	23	67	135	46	0	0.38	0
Cotton	Sorghum	14	76	153	39	0	0.71	0
Sorghum	Cotton	24	46	93	35	0	0.53	2

below the rows. The first rate of N fertilizer (soil-test and yield goal based) and half of second rate (based on two times the first rate) was knifed-in pre-plant (32-0-0, urea ammonium nitrate) at 3 in. depth, 3 in. off the row. The second half of the higher N rate was applied in the same manner at first square in cotton and at the 12 in. height of sorghum. The grain yield goal for sorghum was 4,000 lb/A and the N fertilizer to be added was 70 lb N minus 0 to 24 in. soil NO_3-N, according to regional recommendations. The lint yield goal for cotton was 750 lb/A and the N fertilizer to be added was 90 lb N minus 0 to 24 in. soil NO_3-N, also following regional recommendations. At the start of the study, the soil tested 39 lb NO_3-N/A (0 to 24 in.), 20 parts per million (ppm) Mehlich 3-extractable P (0 to 6 in.), and 0.25 ppm DTPA-extractable Zn (0 to 6 in.) See **Table 1**.

Soil test P in the zero P control plots tended to increase to about 30 ppm for reasons not clear to us. Soil test Zn in the zero Zn control plots remained between 0.25 and 0.30 ppm. Soil test P and Zn in fertilizer addition plots increased in all cases (**Table 1**). Spring extractable NO_3-N in 0 to 24 in. soil depth was on average 39 lb N/A less in plots following sorghum compared to continuous cotton plots.

In the establishment year of the study (2000), sorghum grain yields and cotton lint yields averaged 5,500 and 740 lb/A, respectively (data not shown). Nitrogen, P, or Zn fertilizer responses were not observed. Discussion from this point on will focus on the three seasons of data where rotation data applies, from 2001-2003.

Cotton lint yields were similar following sorghum compared to cotton following cotton for all 3 years (**Table 2**). On average, 39 lb more fertilizer-N/A was applied to the 1X N rate for cotton following sorghum compared to continuous cotton (**Table 1**). In 2001, sorghum grain yields were only about half of the expected level. In 2002 and 2003, sorghum yields were greater and similar to the 4,000 lb/A yield goal. Continuous cotton lint yields equaled the expected goal of 750 lb/A in 2001 and 2003 and cotton in both rotations exceeded the yield goal in 2002. The summer of 2001 was hotter and drier than average and both crops suffered from water stress.

Nitrogen response was observed in all 3 years in cotton following sorghum, but was absent in the cotton-cotton rotation

Table 2. Yields of cotton and sorghum as affected by previous crop and N, P, or Zn fertilizer.

2001 Crop	2000 Crop	2001 Yields	Standard deviation	N response	P response	Zn response
		------- lb/A	-------			
Cotton	Cotton	765	79	No	Yes	No
Cotton	Sorghum	630	79	Yes	No	No
Sorghum	Cotton	2,356	410	No	No	No
2002 Crop	2001 Crop	2002 Yields				
Cotton	Cotton	1,086	42	No	No	No
Cotton	Sorghum	1,096	42	Yes	No	No
Sorghum	Cotton	5,096	487	Yes	No	No
2003 Crop	2002 Crop	2003 Yields				
Cotton	Cotton	763	166	No	Yes	No
Cotton	Sorghum	654	201	Yes	No	No
Sorghum	Cotton	4,095	880	No	No	No

(**Table 2**). Grain sorghum responded to N fertility in 2002 only. Phosphorus response was observed in continuous cotton only, and only in 2001 and 2003. No Zn fertility responses were observed in any rotation or in any year.

Important in understanding N fertilizer response on the Acuff sandy clay loam soil is that about 50 lb N/A is available from mineralization of soil organic matter and from previous cotton crop leaf litter. Sorghum residue, on the other hand, may be biologically "tieing-up" or immobilizing N. This may contribute to the more consistent N fertilizer responses in cotton following sorghum compared to cotton after cotton. As N fertilizer recommendations for these cropping systems are refined, N credits may be needed for cotton leaf-fall and N debits for sorghum residue. Lack of P response in most rotations is probably because soil test P was near the regional recommended critical level of 33 ppm (**Table 1**). Soil Zn was likewise near the critical levels of 0.29 ppm for cotton and sorghum (**Table 1**).

The lack of a positive cotton lint yield response following sorghum compared to mono-cropped cotton was unexpected. In the stormy spring of 2003, the ground cover of about 30% of sorghum residue protected cotton seedlings from wind and blowing sand damage suffered in the continuous cotton. Nevertheless, no positive rotation effect in yield was observed.

Conservation compliance and protection of cotton seedlings is considered another benefit of rotating sorghum with cotton. Soil organic N and C (average of 0.06 and 0.55 %, respectively) analyzed from spring 2002 soil samples did not yet show rotation effects after 3 years and one or two sorghum crops. Soil organic matter buildup, therefore, probably requires several years of cotton-sorghum cropping. BC

Mr. Booker is Assistant Research Scientist, Dr. Bronson (e-mail: k-bronson@tamu.edu) is Associate Professor, and Dr. Keeling is Professor, with Texas A&M University (TAMU), Texas Agricultural Experiment Station. Dr. Trostle is Assistant Professor, TAMU, Texas Cooperative Extension. All are located in Lubbock, Texas.

Nutrient Management of Soybeans with the Potential for Asian Rust Infection

Asian soybean rust has been identified in the U.S., and there are many questions about how it will affect production. The focus has been on fungicides and genetic development. For an article and related information about how plant nutrition might be a factor, check the PPI/PPIC website at: >**www.ppi-ppic.org**<.

Broadcast and Deep Band Placement of Phosphorus for Soybeans Managed with Ridge Tillage

By A.P. Mallarino and R. Borges

Phosphorus (P) fertilization frequently increases yield of soybean on low P-testing soils in ridge-till systems in Iowa. Yields associated with broadcast and banded P applications usually do not differ. However, banded P often increases early P uptake more than broadcast P.

Fourteen trials with soybeans were evaluated in farmer fields managed with ridge-till during 3 years. All fields had been planted to corn the previous year, and the fields had 2 to 7 year histories of ridge tillage. Crop and soil management practices were those used by each farmer, except for P and potassium (K) fertilization. Row spacing was 38 in. except for Site 3, where it was 36 in.

Phosphorus rates were 0, 29, and 115 lb P_2O_5/A, applied as granular triple superphosphate (0-46-0). The highest P rate approximately represented the 2-year rate currently recommended by Iowa State University for the corn-soybean rotation when soil test P (STP) is in the Low interpretation class (9 to 15 parts per million [ppm]), Bray P-1 or Mehlich-3 tests.

Placement methods were broadcast and deep bands. The bands were approximately 6 to 8 in. deep and 1 in. wide. Banding equipment placed the fertilizer either through a vertical slit opened from the top of the ridge or through one ridge shoulder. The coulter-knife combinations opened and closed narrow slits (1 to 2 in.) that caused a minimum amount of disturbance of the ridge and placed the band 2 to 3 in. below the planned seeding depth, approximately under the planned seed row. The broadcast control received no fertilizer and the ridges were not disturbed until planting. The band control received a coulter-knife pass without fertilizer.

Soybean response to direct P application was evaluated in seven trials (Sites 1 through 7). The treatments were applied in the fall (October or November) after harvesting the previous corn crop and before soils had frozen. At the remaining seven trials (Sites 8 through 14), P was applied 1 year earlier (in the fall prior to the previous corn crop).

Soil samples were collected immediately before applying P treatments. Soil samples, comprised of 16 cores each, were collected from a depth of 0 to 6 in. One sample was collected from the ridges and another between the ridges (or valleys). At Sites 1 through 7 (direct fertilization), composite soil samples were collected from each experimental area. At Sites 8 through 14 (residual fertility), separate composite samples were collected from fertilized and unfertilized plots. Samples were analyzed for P with the Bray P-1 test.

Aboveground portions of 10 soybean plants were sampled from each plot at the V5 to V6 growth stages. Total P concentrations in the plant tissue were measured and total P uptake calculated, based on dry matter accumulation. Grain yields were corrected to 13% moisture.

Soybean Grain Yield. As **Table 1** shows, statistically significant grain yield

responses occurred at four sites: Sites 1 and 2 (P applied before soybean) and Sites 10 and 13 (P applied prior to the previous year's corn crop). Yield response to P fertilization reached a maximum at the lowest rate of applied P (29 lb P_2O_5/A). Differences between placement methods were observed at two sites. At Site 2, both placement methods increased soybean yield, but banded P provided a small additional increase. At Site 10, only the broadcast application significantly increased yield. The inconsistent yield response to P placement method is in contrast with the benefit of deep-band K placement shown in a similar Iowa study (Mallarino et al., 2001).

Soils of the four responsive sites tested 7 to 18 ppm Bray P-1, according to average results for soil samples collected in and between the ridges (**Table 2**). Three of the responsive sites tested Very Low or Low and one tested Optimum (16 to 20 ppm) according to current Iowa State University interpretations (Sawyer et al., 2002). Across the entire study, eight sites tested Very Low or Low. According to current soil test interpretations, soybeans grown on soils testing in these ranges would be considered likely to respond to P fertilization. There is a 25% or lower probability of a small response in the Optimum class, for which maintenance fertilization is recommended.

Banding of P for ridge-till soybeans may increase early plant P uptake.

With only one exception, soil samples taken from the ridges were higher in P than those taken between the ridges (valleys). This is consistent with findings from other investigations in Iowa with corn (Mallarino et al., 2001) as well as studies from other states. A reclassification of the sites according to STP results from samples taken solely from the ridges indicated that only six sites tested Very Low or Low (three of which responded significantly to P fertilization) while four tested Optimum (one of which was responsive). These results, and similar results for ridge-till corn not shown in this article, were

Table 1. Soybean grain yield and P uptake at the V5 to V6 growth stages as affected by P fertilization and placement. Data are averages of two application rates (29 and 115 lb P_2O_5) because yields for these two rates were statistically similar at all sites.

P timing	Site	Control yield	Change in soybean grain yield: Broadcast	Change in soybean grain yield: Band	Control P uptake	Change in P uptake: Broadcast	Change in P uptake: Band
		bu/A			10^{-5} lb P_2O_5/plant		
Direct	1	32.3	**3.3**	**5.5**	1.59	**0.39**	**0.47**
	2	44.0	**3.8**	**4.3**	2.04	**0.25**[1]	**1.09**[1]
	3	59.6	2.7	-1.0	4.13	0.06	**0.43**
	4	40.2	-0.3	1.4	1.94	**0.18**	**0.57**
	5	49.2	1.0	-0.9	1.61	-0.20	**0.32**
	6	44.6	0.7	1.4	2.54	-0.02	0.31
	7	45.1	1.1	0.9	3.85	**0.32**	**0.61**
Residual	8	47.4	2.2	3.0	1.98	-0.25	0.10
	9	43.4	-1.8	-0.6	2.67	-0.16	**0.62**
	10	42.8	**1.5**	0.9	2.68	-0.05	**0.48**
	11	43.7	0.1	2.2	3.64	-0.12	0.36
	12	47.7	0.4	1.9	1.90	0.03	0.07
	13	30.7	**2.7**	**2.5**	2.82	0.20	0.08
	14	33.8	4.5	1.4	3.02	-0.15	-0.46

[1]P uptake at the higher P application rate.
Bold type indicates statistically different from the control (p<0.1).

Table 2. Initial Bray P-1 soil test levels and soil pH for various sampling positions. All levels are for samples taken from a 0 to 6 in. depth.

P Timing	Site	Years in ridge-till	Soil test P levels: In ridges	Soil test P levels: Between ridges	Soil test P levels: In and between ridges	Soil pH in and between ridges
			ppm			
Direct	1	6	8	7	7	6.5
	2	5	14	9	11	6.1
	3	2	66	56	61	6.5
	4	5	25	15	20	5.6
	5	3	26	20	23	6.4
	6	4	20	7	14	6.1
	7	6	12	7	10	6.4
Residual	8	7	16	16	16	7.0
	9	4	17	8	13	6.1
	10	6	13	9	11	6.5
	11	6	10	8	9	6.3
	12	4	13	8	11	6.0
	13	5	20	17	18	6.9
	14	5	24	15	20	6.4

used to update Iowa soil sampling recommendations for the ridge-till system (Sawyer et al., 2003). The updated guidelines recommend taking 0 to 6 in. samples from the top and shoulders of the ridges (avoiding valleys) to improve the prediction of yield response. Consideration of deep samples (6 to 12 in., not shown) indicated no benefits in prediction of response. Higher STP results for the ridges may also explain why the lowest rate of applied P (29 lb P_2O_5/A) was sufficient for statistically maximum yields. Only one site (Site 1) tested Very Low in the ridge, and this level was borderline with the Low class.

Early Season P Uptake. Uptake of P by soybean plants at the V5 to V6 growth stage was often influenced by P fertilization (**Table 1**). This was the result of the additive effects of slight (typically insignificant) responses in early plant dry matter accumulation and tissue P concentration (not shown). With the exception of Site 2, P applied at the lower rate (29 lb P_2O_5/A) increased uptake to the same extent as the higher rate (115 lb P_2O_5/A). Consequently, P uptake values reported in **Table 1** represent the lower P application rate, except for Site 2, where reported P uptake is associated with the higher fertilization rate.

When P was applied prior to the soybean year, P uptake increased significantly at most sites (six of the seven sites). At two of these sites (Sites 3 and 5), banded P increased soybean P uptake when broadcast P did not, and banded P led to greater P uptake than broadcast P at other responsive sites. When P was applied prior to corn grown the previous year, P uptake increased significantly at two of the seven sites (Sites 9 and 10). At Site 9, response was observed to banded P only. At site 10, both broadcast and banded P significantly increased P uptake when results were averaged over P rates (not shown). Across all sites, increased P uptake was observed on soils ranging from Very Low to Very High in STP. On average, P uptake was greater for banded P than for broadcast P.

Changes in Soil Test P. To evaluate changes in STP over time, seven sites were examined where P had been applied prior to the previous year's corn crop (Sites 8 through 14). The low P application rate seldom changed STP levels—an expected result because this rate was lower than the P removal rate associated with grain harvest. Consequently, only STP changes associated with the high P rate (115 lb P_2O_5/A) are presented. When fertilizer P was broadcast, STP levels in the ridge did not

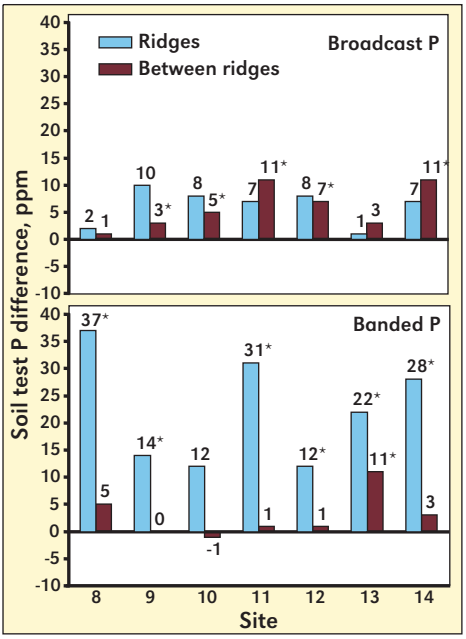

Figure 1. Effect of broadcast and banded P (115 lb P_2O_5/A) on soil-test P of ridges and areas between ridges (valleys) measured after crop harvest. Differences presented are between fertilized and unfertilized treatments. Values followed by an asterisk represent statistically significant ($p<0.1$) changes due to fertilization when compared to unfertilized treatments.

change significantly compared with the non-fertilized control. However, STP levels in the valleys between the ridges increased significantly at five sites (**Figure 1**).

Banded P significantly increased STP in the ridge at six of the seven sites (**Figure 1**). However, it increased STP between the ridges at only one site (Site 13).

The way in which P placement alters STP has implications on environmental nutrient management. Concentrated surface water flow occurs between ridges, mainly on trafficked areas. Because banded P seldom increases STP between ridges and also places P below the surface, this placement method is expected to reduce the chances for offsite P transport into water bodies.

Summary

Soybean yield response to P fertilization was frequent in low-testing soils, infrequent in soils testing Optimum, and did not occur in high-testing soils. Collecting soil samples solely from ridges improved the prediction of yield response to applied P. When responses occurred, STP in the ridges was 20 ppm or less. The P placement method did not influence yield response consistently, which was in contrast with the clear benefits of deep K placement observed in parallel Iowa studies with corn and soybean. However, early plant uptake of P by soybean was increased more frequently and to a greater extent by banded P than by broadcast P. Furthermore, banded P increased STP primarily in the ridges, while broadcast P increased STP levels primarily in the soil between the ridges. Therefore, banded P may not increase grain yield more than broadcast P, but it is more likely to stimulate early plant P uptake and is a viable option for reducing the risk of P loss from ridge-till fields. BC

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Dr. Borges is Assistant Professor, Department of Agronomy, University of Wisconsin, Madison.
PPI/FAR Research Project IA-11F

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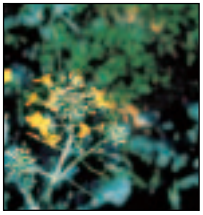

Management of High Yielding Canola Culitvars

By S. Brandt, D. Ulrich, G. Lafond, R. Kutcher, S. Malhi, and A. Johnston

To maximize seed yield, high yielding canola cultivars should be receiving more fertilizer than is currently being applied on the northern Great Plains.

Registered open pollinated and hybrid canola currently grown on the northern Great Plains provide higher yield potential than conventional varieties for farmers. However, the management strategies necessary to achieve optimum yield are not well understood. Nutrients frequently restrict the yield of canola and it is reasonable to expect that higher fertilizer application rates would be required to support higher yields possible with newer cultivars.

Seed of hybrid canola cultivars is several times more expensive than open pollinated types, and therefore reduced seeding rates is seen as a possible area for cutting input costs. Research trials were conducted over a three-year period to evaluate whether combinations of fungicides, seed rates and fertility levels needed to be altered, and whether increased rates of fertilizer nitrogen (N) would be required to optimize the yield of newer high yielding canola cultivars.

Field trials were conducted in Saskatchewan at Melfort (clay), Indian Head (heavy clay), and Scott (loam), between 1999 and 2001. Canola was direct seeded into wheat stubble using low disturbance openers with on row packers. At seeding, N was applied as banded urea, along with a phosphorus (P), potassium (K), and sulfur (S) fertilizer blend. Treatments in the experiment were two cultivars (hybrid and open pollinated), three fertility levels that supplied 2/3, 1.0, and 1 1/3 times a target level of soil test recommendation for N, P, K, and S, and three seeding rates: 2.5, 5.0, and 7.5 lb/A. A fungicide treatment included an application of Ronilan EG (vinclozolin) to control sclerotinia stem rot. At Melfort only, there was an additional application of Quadris (azoxystobin) for blackleg. Background levels of N and S to 24 in. depth, and P and K to 6 in., were measured each year to establish residual soil fertility. Residual soil N varied from 18 to 52 lb/A depending on location and year.

In a second experiment, six N rates were applied (0, 27, 54, 80, 107, and 134 lb/A) as urea using the same open pollinated and hybrid cultivars as above. Residual soil N varied from 22 to 67 lb/A. A single rate of P-K-S blend was applied, with a seed rate of 6.2 lb/A. Growing season moisture conditions were above normal in 1999, near normal in 2000, and below normal in 2001.

The two cultivars responded consistently to seeding rate, nutrient level, and fungicide across all location and years, despite the hybrid producing greater seed yield than open pollinated cultivar. Because the same weight of seed was sown for both cultivars, and the seed size for the hybrid was greater than that of the open pollinated cultivar by an average of 40%, the number of hybrid seeds sown was lower. This was the major factor affecting cultivar differences in plant density (**Table 1**).

Generally, the hybrid had lower densities than the open pollinated cultivar, while the reverse occurred for percent establishment (% of seeds sown that emerged).

Table 1. Plant densities, plant establishment, biomass production, and seed yield of hybrid and open pollinated canola at Scott, Melfort, and Indian Head during 1999-2001. (Data are the mean of three seed rates and three fertility levels).

Factor[1]	Hybrid	Open Pollinated
Plant density, no./sq yd	67b	79a
Percent establishment, % of seed planted	53	47
Biomass yield, tons/A	3.32a	2.95b
Grain yield, bu/A	32.6a	29.0b

[1]Values in rows followed by a different letter are significantly different at p=0.05.

Biomass and grain yield with the hybrid was similar or higher than the open pollinated cultivar at all locations and years, and averaged 12% higher. With above normal moisture during 1999 grain yield differences between cultivars were relatively small (0.9 bu/A), while in the dry year 2001 grain yield differences between cultivars were quite large (5.5 bu/A). These results provide good evidence that canola hybrids do not require more available moisture to express a yield advantage, and possibly are more drought tolerant.

Both increased seed rate and fertility level generally increased yield (**Table 2**). However, for the low fertility treatment, yield increased when seed rate was increased from 2.5 to 5.0 lb/A, with no further increase at 7.5 lb/A. Similarly, at 2.5 lb/A seed rate, yield was higher for the mid than low fertility level, but further increases in yield were not detected for the high fertility treatment. At the 5.0 and 7.5 lb/A seed rates yield continued to increase with each increase in fertility. This provides strong evidence that higher plant densities are required to take advantage of higher fertility, and vice versa. The lack of an interaction of cultivar with seed rate or fertility level suggests that both canola cultivars require similar seed rates and fertility to optimize yield.

In the N rate trial, the interaction of cultivar with location-year and N rate was significant. The general trend was for the yield of the hybrid to be equal to, or greater than, the yield of the open pollinated cultivar at all N rates. Under dry conditions in 2001, seed yield of both cultivars was maximized with 105 lb/A of applied N (**Figure 1**). But yield was not maximized even with the highest N rate under near normal moisture conditions in 2000. Averaged over all location-years, the seed yield of the hybrid canola was maximized at 40 bu/A with 119 lb/A of fertilizer N/A, while the yield of the open pollinated was maximized at 34 bu/A with 132 lb N/A. The hybrid outyielded the open pollinated cultivar at all levels of applied N indicating that it used N more efficiently. The relative difference in seed yield between the two cultivars increased as N supply increased, yielding 10% more without N application and 17% more when 98 lb N/A was applied.

Table 2. Seed yield (bu/A) with three fertility rates and three seed rates averaged across 7 location-years. (Means for two cultivars and two fungicide treatments).

Fertility level	Seed rate, lb/A[1] 2.5	5.0	7.5
Low	26.8e	30.1d	29.8d
Mid	29.1d	31.9c	33.6b
High	29.9d	33.7b	35.4a

[1]Values in rows followed by a different letter are significantly different at p=0.05.

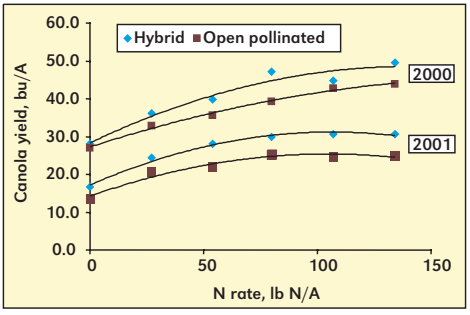

Figure 1. Seed yield of hybrid and open pollinated canola as a function of applied N under normal to above normal moisture conditions in 2000 and below normal moisture conditions in 2001.

In this study, despite an average yield advantage of 3.6 bu/A for the hybrid over the open pollinated cultivar and greater advantage under dry conditions, both cultivars were consistent in their response to seed rate, nutrient level, and fungicide. Fungicide generally failed to increase yield in our trials since disease levels were insignificant. While yields generally increased with increasing fertility and increased seed rate, the seed yield response to high fertility occurred only with high seed rates.

The N response results indicate that target N levels for canola grown on wheat stubble in moisture-limited environments should be the same for a higher yielding hybrid as they are for a high yielding open pollinated cultivar. The results also suggest that high yielding cultivars should be receiving more fertilizer to maximize seed yield than is currently being applied by many farmers. When adequately fertilized with N, greater N use efficiency of hybrid canola results in greater seed yields than the open pollinated cultivar at all location-years, despite a higher seed cost. BC

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Soil Fertility and Fertilizers—
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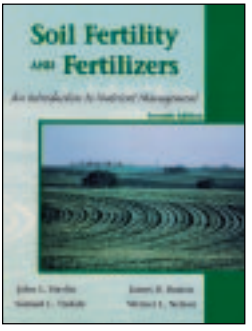

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MISSOURI

Rice Potassium Nutrition Research Progress

By David Dunn and Gene Stevens

Recent Missouri research has shown significant rice response to potassium (K) fertilization applied pre-plant or at mid-season on silt loam soils. Soil test K interpretations and fertilizer recommendations for rice were increased.

Missouri has a long history of rice production, going back to 1910 when the crop was first grown in the southeast region of the state. From this 40-acre start, rice acreage has increased steadily over the years to over 200,000 acres currently. The statewide average yield was 110 bu/A in 1997 and increased to over 141 bu/A in 2004. Traditionally, nitrogen (N) management has been given top priority by farmers. But with increased yields and rotations with soybeans, K fertility is increasingly being recognized as a yield limitation in some Missouri rice fields.

Research conducted by the University of Missouri is now highlighting the importance of K in rice production. Historically, soil test-based fertilizer recommendations for rice grown in Missouri were adapted from work in the surrounding states of Arkansas and Mississippi. As production increased, a need for soil test recommendations specific to Missouri soils was recognized. Missouri uses a 1 N ammonium acetate (NH_4OAc) extraction for K, while Arkansas uses the Mehlich-3 extractant and Mississippi uses the Lancaster extractant. Initial soil testing and soil fertility research in Missouri focused on improving soil test recommendations for K and has now expanded to the diagnosis and correction of K deficiency at mid-season.

Rice production in the Bootheel region of southeast Missouri is on silt loam soils west of Crowley's Ridge, and clayey soils generally found to the east of Crowley's Ridge. The Sharkey clay soils (Vertic Haplaquepts) generally have high native available K levels (500 to 600 lb K/A) and do not require K fertilization. Many of these clayey soils have been recently land leveled and have a limited history of rice production. If intensive rice and soybean production continues on these soils, they will eventually require K fertilization. The silt loam to silty clay loam soils with a longer history of rice production often require K fertilization. This article focuses on drill-seeded rice grown on silt loams using the delayed-flood management system (i.e., flooded at the 5-leaf stage, 20 to 30 days after emergence, after urea is applied to a dry soil surface).

Soil test K management. Potassium deficiency in rice can reduce grain yields and increase lodging. Visual symptoms of K deficiency in rice first appear in older leaves (**Figure 1**). These symptoms include

Figure 1. Brown areas on leaf margins and tips in rice are a visual indicator of K deficiency.

a yellowing of leaf tips, decreased disease resistance, and reduced yields. Increased stalk strength and decreased lodging are associated with proper K nutrition. When this study began, the University of Missouri soil test critical level for K (lb/A) was 5 x cation exchange capacity (CEC) based on a 1 *N* NH_4OAc extraction. During the late 1990s, Missouri rice producers began growing Baldo, a variety grown for a specialized Mediterranean and west Asian market. This variety is much taller than the semi-dwarf varieties typically grown. Agronomists from Italy recommended applying mid-season K applications on Baldo to increase stalk strength and reduce lodging.

To test this management strategy under Missouri conditions, a 2-year evaluation of pre-plant and midseason K fertilization strategies was undertaken on a Crowley silt loam soil (Typic Albaqualf) having 110 lb NH_4OAc extractable K/A. A single pre-plant (48 lb K_2O/A) application was compared to two 24 lb K_2O/A applications at mid-season, using potassium chloride (KCl) as the K source. Two foliar treatments were also evaluated: 1) two applications of 12 lb K_2O/A as potassium nitrate (KNO_3), and 2) two foliar applications of urea (1.3 lb N/A). The urea treatment was included to allow separation of the effects of N and K in the KNO_3 treatment. The results for the foliar urea treatment were identical to that of the untreated check and will not be discussed further. Response of Baldo was compared to Bengal, which is considered susceptible to K deficiency.

The results of these investigations were: 1) pre-plant and mid-season K applications increased rice yields on a soil where K fertilization was not expected to increase yields (**Figure 2**), 2) Visual deficiency symptoms were sometimes observed at mid-season. Tissue K analysis of flag leaves at mid-season did not reveal significant differences between treatments (data not shown) and was not an effective tool for diagnosing K deficiency in rice, and 3) Lodging of Baldo was significantly reduced by foliar applications of KNO_3 at midseason (**Figure 3**). No lodging of Bengal was observed.

These findings prompted a more detailed K rate study beginning in 2001. Methods to diagnose mid-season K deficiency were also evaluated as part of the study. Three rates of pre-plant K fertilization were compared (0, 50, and 200 lb K_2O/A). When relative yields were compared, the 50 lb K_2O/A rate provided 95% of the maximum yield (**Figure 4**). As a result of this study, the critical level for soil test recommendations was increased to 125 lb of available K/A + (5 x CEC) in 2003. Comparison of our results with those in Arkansas, Louisiana, and Mississippi indicate that this new soil test K interpretation level is similar to the interpretations in those states.

Monitoring rice tissue K. Plant tissue samples were collected for K analyses from

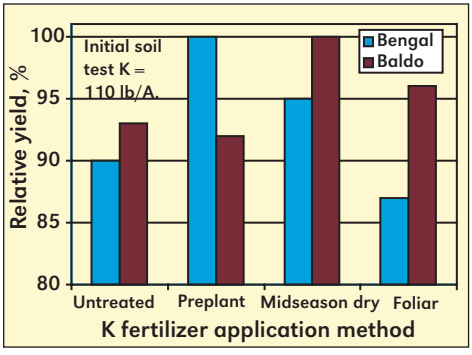

Figure 2. Relative yields for K treatments of Baldo and Bengal rice averaged across 1999 and 2000 at Qulin, Missouri.

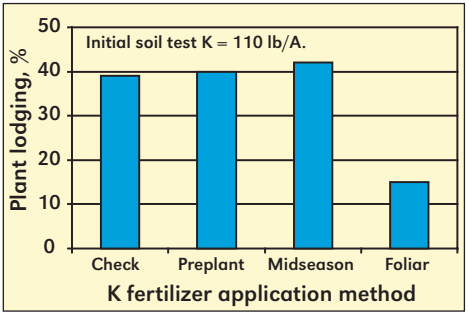

Figure 3. Effect of K treatments on lodging of Baldo rice variety averaged across 1999 and 2000 at Qulin, Missouri.

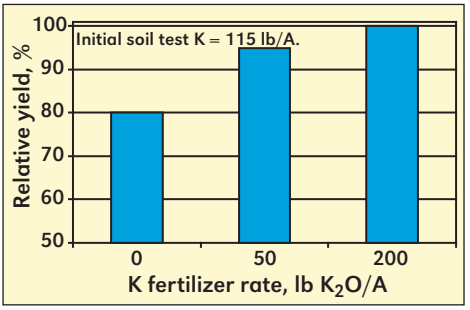

Figure 4. Effect of preplant K fertilizer rates on relative rice yields in tissue K monitoring experiments in 2002 and 2003 at Qulin, Missouri.

each plot every two weeks during the growing season beginning at first tiller and continued until harvest. Samples were divided into plant components (i.e. upper leaf, lower leaf, stalk, and whole above-ground plant). Correlation analyses were made between yields and plant tissue K levels (**Table 1**). Plant tissue testing clearly showed the effect of K fertilization. At first tiller, only the whole plant was analyzed. At this growth stage, untreated check plants (0 K) had lower K concentrations than plants that received 50 and 200 lb K_2O/A. At internode elongation, the rice plants were divided into the following plant parts: stem, flag leaf, lowest leaf, and whole plant.

Correlations between plant K and yield were generally better in 2003 than 2002 (**Table 1**). The best correlation in 2003 was for whole plant at first tiller growth stage. Tissue K levels of lower leaves were better correlated to grain yields than were K levels of flag leaves. Leaf K concentrations were greatest in the upper leaves, but the lowest leaves showed the most differences between K fertilizer treatments. At internode elongation, all of the leaves had K levels above the critical sufficiency level of 1.0%. Potassium content of stems also reflected K treatment differences at panicle initiation. Whole plant tissue K content increased with increasing K fertilization. Stem K content at 10% heading also closely reflected K treatment differences.

Table 1. Correlation of plant tissue K levels with grain yields in 2002 and 2003 at Qulin, Missouri.

		r^2 value	
Growth stage	Plant part	2002	2003
First tiller	Whole	0.22	0.54
Internode elongation	Whole	0.27	0.37
	Flag leaf	0.07	0.23
	Lowest leaf	0.38	0.39
	Stem	0.07	0.30
10% Heading	Whole	0.25	0.32
	Flag leaf	0.06	0.07
	Lowest leaf	0.45	0.39
	Stem	0.11	0.41
	Head	0.001	0.003

The K content of heads was affected erratically by K fertilization, and K levels of heads were poorly correlated to yields.

In summary, tests showed that preplant and mid-season K applications increased rice yields on soils where K fertilization was not previously expected to have that effect. This prompted the University of Missouri to increase critical soil test K (lb/A) from 5 x CEC to 125 lb extractable K/A + (5 x CEC). Tissue testing showed that K concentrations in lower rice leaves were better for measuring K status than tissue K in flag leaves. BC

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The seventh national/international InfoAg Conference is set for July 19 to 21 in Springfield, Illinois. Co-organized by PPI and the Foundation for Agronomic Research (FAR), the program will focus on a broad range of crop and soil management systems. More details will be available at the website: >**www.infoag.org**<. Or contact Dr. Harold F. Reetz by e-mail at: hreetz@ppi-far.org.

SOUTH CAROLINA

Differences in Potassium Requirement and Response by Older and Modern Cotton Varieties

By J.J. Camberato and M.A. Jones

Late-season potassium (K) deficiencies have occurred in many South Carolina cotton fields over the past few years, with some varieties showing deficiency symptoms more frequently than others. Newer, higher-yielding, fast-fruiting cotton varieties appear to respond more favorably to applied K than older varieties, and may benefit from increased application rates.

In recent years, late-season K deficiencies have been observed in many cotton fields across South Carolina. Some varieties have appeared to show K deficiency symptoms more frequently than others. New, higher-yielding, earlier-maturing cotton varieties develop more of their total boll load over a shorter period of time, which can lead to a more condensed boll filling period and an increased demand for the uptake and mobilization of K from the soil and leaf to the developing lint—from 2 to 4 lb K/A/day.

Since K is the primary osmoticum for fiber development and provides the turgor pressure necessary for fiber elongation, optimum cotton yields and fiber quality are highly dependent upon an adequate supply of K throughout the growing season. Late-season K deficiencies appear to be extremely detrimental to cotton, with reduced fiber quality (especially fiber length, strength, and micronaire) and lint yield, often occurring as a result of late-season K deficiencies.

Excessive drying of the upper soil layers renders K unavailable to the crop, and deep soil layers have little K because downward leaching is limited in relatively high cation exchange capacity soils. Soils in the Coastal Plain region of South Carolina are much different than those in the Mississippi River Delta, and the distribution and availability of K are also quite different. Coastal Plain soils typically have accumulations of K in clayey subsoil layers due to leaching of K incorporated into sandy surface soil layers. The extent of downward K movement during the growing season and access to subsoil K likely governs K availability in Coastal Plain soils. Current K fertilizer recommendations in South Carolina are based on pre-season K levels of the topsoils that are adjusted by depth and K content of the subsoil. The data establishing the subsoil K adjustment to fertilizer recommendations preceded development of these high K-demanding cotton varieties. Research was conducted to determine if current soil sampling procedures and recommendations are valid to optimize yield of modern cotton varieties.

A replicated field experiment was conducted in 2002 and 2003 at the Pee Dee Research and Education Center located in Florence on a Norfolk-Bonneau soil complex (Typic Kandiudult-Arenic Paleudult) identified as K deficient in 2001. The plow layer, upper 8 in. of the E-horizon, and upper 8 in. of the B-horizon were sampled prior to initiating the experiment and analyzed for Mehlich-1 K and soil pH. Depth to the B-horizon was also determined. An attempt was made to optimize yields utilizing a center-pivot irrigation system, a split application of 120 lb N/A,

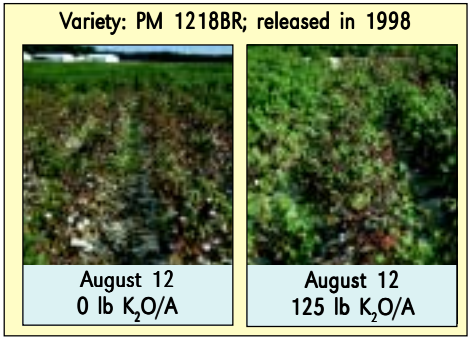

Figure 1. Visual response of cotton variety PM 1218BR to 125 lb K_2O/A.

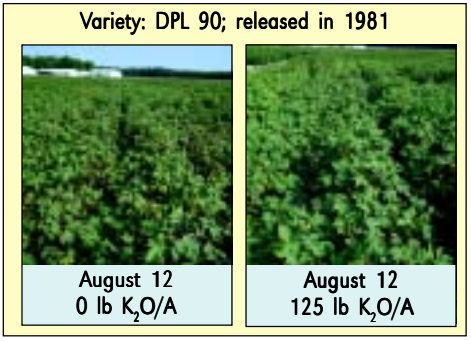

Figure 2. Visual response of DPL 90 to 125 lb K_2O/A.

and intense pest control.

Potassium treatments were broadcast prior to planting at 0, 50, 75, 100, and 125 lb K_2O/A. Five cotton varieties released between the years 1915 and 2001 (Dixie Triumph, 1915; DPL 90, 1981; DES 119, 1985; Paymaster 1218BR, 1998; and DPL 555BR, 2001) were evaluated. The experimental design was a split-plot with K fertilization rate as the whole plot (20 rows wide by 40 ft. long) and variety as the split plot (4 rows wide by 40 ft. long).

Only the center two rows were used for plant tissue and lint harvest. Leaf and petiole samples were obtained every 2 to 3 weeks from first bloom through cutout to monitor K status of the cotton plant. The sap from 20 petioles was squeezed out, and K determined with a Cardy K^+ meter. Leaf tissue was dried, ground, and analyzed for nutrient content by standard laboratory procedures. Weekly white bloom counts from one middle row were conducted. Destructive plant sampling (1 ft. of row) occurred at early squaring (matchhead square) and at cutout, in order to determine changes in dry matter partitioning, boll development, and relative maturity levels. At harvest, plants were mapped to assess changes in fruit distribution throughout the canopy, and plots were machine-harvested. Lint yield, gin turnout, and fiber quality were determined. Response to K fertilization was examined in relation to K fertilization rate and intensity of the boll-filling period (old to new varieties) as it is altered by the supply and distribution of soil K.

Cotton growth and development was significantly altered by the K treatments, and visible differences in deficiency symptoms in the field occurred among varieties and K rates (**Figures 1 and 2**). Significant premature leaf defoliation occurred at lower K application rates, but varied with variety (**Figure 3**). Leaf and petiole K levels were positively related to the sum of the initial soil K level of the A-horizon plus 50% of the K fertilization rate (**Figures 4 and 5**). Including E- or B-horizon K levels and/or a higher or lower percentage of K fertilization rate did not improve these relationships. Leaf K appeared to be a better indicator of K supply than petiole K, but was also more affected by growth stage compared to petiole measurements. Leaf K concentrations were low throughout boll

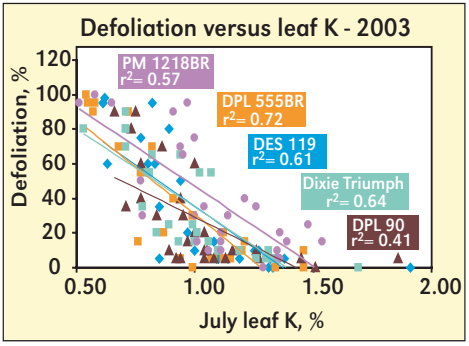

Figure 3. Relationship between premature leaf defoliation and leaf K in July.

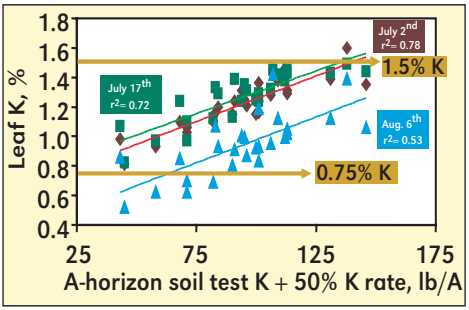

Figure 4. Relationship between percent leaf K and soil test K levels in the A-horizon plus 50% of the applied K rate. Sufficiency range is 1.5 to 3.0% K at early bloom to 0.75 to 2.5% at late bloom.

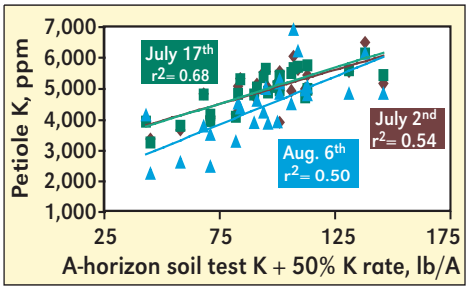

Figure 5. Relationship between petiole K and soil test K levels in the A-horizon plus 50% of the applied K rate.

development (especially with the low K fertilizer treatments), attaining deficiency levels of less than 1.5% at early bloom and less than 0.75% at cutout. All varieties responded favorably to increased levels of leaf K, but the recently released, higher-yielding varieties such as PM 1218BR and DPL 555BR responded more to K than older, lower-yielding varieties such as Dixie Triumph, DES 119, and DPL 90 (**Tables 1 and 2**). Lint yields increased 400 to 800 lb/A with each 1% increase in leaf K. Yields of newly released varieties increased more than older varieties.

Based on these recent results, new, higher-yielding, fast-fruiting cotton varieties may respond favorably to higher rates of applied K than older varieties. BC

Table 1. Variety response to K supply – 2002.

Variety	Leaf %K (8/6) with high K	Change in lint yield per % change in leaf K, lb/%K	Lint yield, lb/A[1]
Dixie Triumph	1.02	409	613
DPL 90	1.26	497	845
DES 119	1.06	666	900
PM 1218BR	1.20	543	962
DPL 555BR	1.25	678	1,056

[1]Average across all K rates.

Table 2. Variety response to K supply – 2003.

Variety	Leaf %K (8/6) with high K	Change in lint yield per % change in leaf K, lb/%K	Lint yield, lb/A[1]
Dixie Triumph	1.18	458	341
DPL 90	1.19	428	594
DES 119	1.21	718	543
PM 1218BR	1.30	528	571
DPL 555BR	1.16	819	643

[1]Average across all K rates.

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PPI/FAR Research Project SC-13F

North Central Extension-Industry Conference Proceedings Available

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A new publication from PPI titled *Be Your Own Cotton Doctor* offers cotton growers and their advisers and consultants a new tool. The 8-page booklet features 40 color illustrations showing typical symptoms of nutrient deficiencies, toxicities, diseases, and other disorders in cotton 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.

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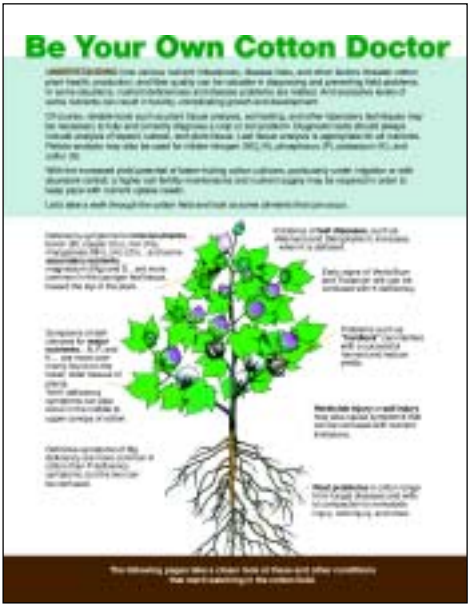

United States Postal Service

Statement of Ownership, Management, and Circulation

1. Publication Title	2. Publication Number	3. Filing Date
Better Crops with Plant Food	0 0 0 6 - 0 0 8 9	11-30-04
4. Issue Frequency	5. Number of Issues Published Annually	6. Annual Subscription Price
Quarterly	4	$20.00 (free to subscrib

7. Complete Mailing Address of Known Office of Publication (Not printer) (Street, city, county, state, and ZIP+4)
655 Engineering Dr. Ste 110
Norcross, GA 30092

Contact Person: Don Armstrong
Telephone: 770-825-8080

8. Complete Mailing Address of Headquarters or General Business Office of Publisher (Not printer)
SAME

9. Full Names and Complete Mailing Addresses of Publisher, Editor, and Managing Editor (Do not leave blank)

Publisher (Name and complete mailing address)
Potash & Phosphate Institute
655 Engineering Dr. Ste 110
Norcross, GA 30092

Editor (Name and complete mailing address)
Donald L. Armstrong
655 Engineering Dr. STE 110
Norcross, GA 30092

Managing Editor (Name and complete mailing address)

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Potash & Phosphate Institute	655 Engineering Dr. Ste 110 Norcross, GA 30092

11. Known Bondholders, Mortgagees, and Other Security Holders Owning or Holding 1 Percent or More of Total Amount of Bonds, Mortgages, or Other Securities. If none, check box ☐ None

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12. Tax Status (For completion by nonprofit organizations authorized to mail at nonprofit rates) (Check one)
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☒ Has Not Changed During Preceding 12 Months
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PS Form 3526, October 1999 (See instructions on Reverse)

13. Publication Title: Better Crops with Plant Food
14. Issue Date for Circulation Data Below: 2004, No 4 - October

15. Extent and Nature of Circulation		Average No. Copies Each Issue During Preceding 12 Months	No. Copies of Single Issue Published Nearest to Filing Date
a. Total Number of Copies (Net press run)		15,075	15,075
b. Paid and/or Requested Circulation	(1) Paid/Requested Outside-County Mail Subscriptions Stated on Form 3541. (Include advertiser's proof and exchange copies)	3,579	3,599
	(2) Paid In-County Subscriptions Stated on Form 3541 (Include advertiser's proof and exchange copies)	-0-	-0-
	(3) Sales Through Dealers and Carriers, Street Vendors, Counter Sales, and Other Non-USPS Paid Distribution	6,488	6,259
	(4) Other Classes Mailed Through the USPS	2,206	1,873
c. Total Paid and/or Requested Circulation (Sum of 15b. (1), (2),(3),and (4))		12,233	11,731
d. Free Distribution by Mail (Samples, complimentary, and other free)	(1) Outside-County as Stated on Form 3541	388	404
	(2) In-County as Stated on Form 3541	-0-	-0-
	(3) Other Classes Mailed Through the USPS	50	50
e. Free Distribution Outside the Mail (Carriers or other means)		1,317	1,319
f. Total Free Distribution (Sum of 15d. and 15e.)		1,755	1,733
g. Total Distribution (Sum of 15c. and 15f)		13,988	13,504
h. Copies not Distributed		1,087	1,571
i. Total (Sum of 15g. and h.)		15,075	15,075
j. Percent Paid and/or Requested Circulation (15c. divided by 15g. times 100)		87%	86.8%

16. Publication of Statement of Ownership
☒ Publication required. Will be printed in the 2005 No 1 issue of this publication. ☐ Publication not required.

17. Signature and Title of Editor, Publisher, Business Manager, or Owner
Donald L. Armstrong, Editor — Date: Nov. 30, 2004

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CALIFORNIA

What Is Sustainable Agriculture and How Do We Do It?

By Craig Kallsen

"Sustainable agriculture" should not be considered a separate system from the current production agriculture system in the U.S. Artificial boundaries will not be conducive to meeting the goals of sustainable agriculture or to meeting the challenges of providing food, fiber, and fuel needed by the world's growing population.

The Sustainable Agriculture Research and Education Program of the USDA's Cooperative State Research, Education, and Extension Service defines sustainable agriculture as an agricultural production and distribution system that:

1. Achieves the integration of natural biological cycles and controls.
2. Protects and renews soil fertility and the natural resource base.
3. Optimizes the management and use of on-farm resources.
4. Reduces use of nonrenewable resources and purchased production inputs.
5. Provides an adequate and dependable farm income.
6. Promotes opportunity in family farming and farm communities.
7. Minimizes adverse impacts on health, safety, wildlife, water quality, and the environment.

The objectives of sustainable agriculture programs are admirable and each of the points listed above expresses a very worthy objective. Being against sustainable agricultural as expressed in these objectives is akin to being against motherhood and apple pie. However, we have to be careful in our enthusiasm for the objectives of sustainable agriculture that we don't encourage a backlash against agriculture in general, that is harmful to the food distribution system and human nutrition. Some enthusiastic supporters of sustainable agriculture are creating an image of agriculture as it is currently conducted in the U.S. as a 'nonsustainable agriculture'. Creation of artificial boundaries between us (strong adherents of sustainable agriculture objectives) and them (other people who do agriculture) is not conducive to progress in meeting the goals of sustainable agriculture.

The fact that we defined some desirable objectives and loosely encompassed them under the term 'sustainable' agriculture should not suggest that our current agricultural system in the U.S. is unacceptable, antiquated, or evil. American agriculture, while far from perfect, is productive, evolving ecologically, and remains an important breadbasket to the world. Agriculture within the confines of the U.S., and even more so in many western European countries where population growth is negative, becomes more sustainable every year.

We do not want to get into playing the game of who is more sustainable than whom. While a sustainable agriculture is essential for maintaining long-term human existence, problems with its establishment are in the details. Putting full effort into meeting one of the objectives of sustainable agriculture may infringe negatively on one of the other objectives. For example, the development of the tomato harvester maximized the use of on-farm resources (such as capital) and improved farm income for some tomato-growing farm families while at the same time reduced employment opportunities for others who

depended on hand-picking for their livelihood. Which uses less non-renewable energy—a single tomato picking machine, or 60 people driving to the farm to harvest tomatoes by hand? Who decides what is an adequate and dependable farm income? The objectives of sustainable agriculture are not as straightforward as they appear and conducting a more sustainable agriculture is just as much of a balancing act among environmental, economic, and social issues as is any other human enterprise.

Many of the success stories described for programs supporting sustainable agriculture describe small family farm enterprises. Typically these families have found a niche that is vertically integrated in that they both produce food or fiber and take a more active role in marketing it. Often they receive a price premium for their produce because it was grown organically with natural pesticides and fertilizers or, at least, with reduced levels of synthetic pesticides and fertilizers. While these enterprises are admirable, there is no way that everyone who desires to make a living from agriculture can survive economically doing this. If too many people get in the niche, it either is no longer a niche, or it is overly crowded and somebody is no longer going to have an adequate or dependable income.

Large corporate farms are often accused of being contrary to the objectives of most if not all of the goals of sustainable agriculture. In fact, some of the most innovative and environmentally friendly farming practices are being conducted by large farming operations in the San Joaquin Valley of California. These practices include integrated pest management, water protection and storage, the creation of good paying jobs with reduced drudgery and with reduced potential for repetitive work injuries, and the use of more energy efficient machinery that comes with taking advantage of scale.

There is a potential danger of having an agriculture that gets too far out ahead of the rest of American society and the world in sustainability. For example, the world's current use of oil is not sustainable. Oil reserves are down and world stockpiles of agricultural commodities are the lowest they have been for years. The forecast increase in world population is not sustainable. World agriculture, sustainable or not, must sustain the world's population growth, sustainable or not. Somehow American agriculture will have to help support the huge population growth forecast for many of the world's developing countries. To feed the world's burgeoning population over the next 50 years or so, we need the ability to harness the productivity of synthetic fertilizers, pesticides, and groundwater supplies, even if the use is nonsustainable. Sustainability, and the health of the world environment, may have to be compromised to some extent in the short-term, if people are to be fed in the next few decades. Agriculture is just a piece, albeit an important piece, of society. For sustainability to occur in agriculture, society, as a whole, must use its resources of air, water, land, energy, and all else in a more sustainable way.

To insist that farmers in the U.S. become fully sustainable immediately, when farmers in the rest of the world are not, puts American farmers at a real and distinct economic disadvantage. Sustainable agricultural objectives should be guidelines for all of agriculture. To try to make these guidelines into a separate farming system or a philosophy of life is to unduly complicate the already fragile balance that feeds the world and keeps food affordable.

Sustainable agricultural programs have rediscovered and increased the knowledge base of practices that farmers used to maintain their productivity before the advent of the 20th century. **The safest, most secure, and prudent changes that agriculture accomplishes toward greater sustainability occur from within the agriculture system, one producer at a time, and not from attempts to force premature and possibly catastrophic changes en masse from the outside.** BC

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Nutrient Exclusivity in Organic Farming—Does It Offer Advantages?

By H. Kirchmann and M.H. Ryan

The following aims are associated with organic farming: to produce healthier foods, to be environmentally friendly, and to be more sustainable. Organic principles are applied in the belief that they are the best way to achieve these aims. However, a critical analysis of organic fertilization practices does not support this belief.

Fertilization within organic farming is designed to maintain soil fertility, but not to directly feed plants. Nutrients are applied in organic or low solubility inorganic forms in the belief that plants will obtain balanced nutrition through the actions of soil microbes. The exclusion of synthetic fertilizers in organic farming has been motivated by various arguments: lower crop quality, faster humus-breakdown, and a non-synchronized supply to crops. Furthermore, philosophical views about life are a basic fundament for organic principles (Kirchmann 1994).

What yields are achieved on organic farms and what area of land is required to sustain these yields?

A number of long-term field trials in Europe reveal that crop yields are on average 20% lower in organic systems that combine crops with animals and 33 to 45% lower in organic systems with crops alone, compared to their conventional counterparts (**Table 1**). Studies of farms under long-term organic management in Australia reveal yields of individual crops as substantially lower than on conventional neighboring farms (**Table 1**). Lower yields reflect either a lower fertilizer input and/or a lower uptake efficiency of nutrients from fertilizers.

The low yields on organic farms mean that to produce the same amount of food as conventional farms, more land is needed. For instance, to sustain food production in Europe, widespread adoption of organic farming without animals would require an increase in land area of 64%, assuming crop production is reduced by 39%, and adoption of organic systems with animals would require an increase in land area of 25%. If conventional farming is widely replaced by organic farming, clearing of wildlife habitats and conversion of natural and semi-natural ecosystems into agricultural land is unavoidable in systems that did not originally produce a food surplus. Thus, biodiversity will be reduced. But the main concern is that lower yields would increase the size of the world hunger map.

Can an enhanced soil biological community improve availability of plant nutrients in organic systems?

It is often assumed that the soil biological community will be enhanced in response to organic management, developing a greater capacity to supply plants with nutrients from organic and poorly soluble inorganic sources. One component of the soil biological community that occur consistently more abundantly on organic farms are arbuscular mycorrhizal fungi, as soluble phosphorus (P) fertilizers suppress their occurrence on conventional farms (Ryan et al., 2000). Arbuscular mycorrhizal fungi are best known for their ability to enhance host plant uptake of P and other nutrients. However, studies of organic crops and pastures in southern

Table 1. Mean yields and N inputs from long-term farming system experiments in Europe and from paired commercial farms under long-term organic and conventional management in Australia.

Experiment and farming system	Yield, t/ha		Yield decrease, %	N input, kg/ha/yr		Reference
	Organic	Con.		Organic	Con.	
Norway: Apelsvoll-site (8 years)						
Crops plus animals				121	227	Korsaeth and Eltun , 2000
Barley, oats, wheat	3.7	5.0	26			Eltun et al., 2002
Three-year forage crop	8.3	10.7	22			
Green fodder	7.1	7.6	7			
Switzerland: DOK-trials (24 years)						
Crops plus animals				105	138	Spiess et al., 1993
Winter wheat	4.1	4.5	10			Besson et al., 1999
Three-year forage crop	11.5	14.0	18			Mäder et al., 2002
Potato	30.0	48.0	38			
Sweden: Skåne-trials (12 years)						
Crops only				59	130	Ivarson and Gunnarsson, 2001
Winter wheat	3.7	6.3	41			
Potato	21.4	38.0	44			
Crops plus animals				110	185	
Winter wheat	4.1	6.4	36			
Two-year forage crop	6.6	9.3	29			
Australia: New South Wales (30 years; One pair of farms)						
Crops plus animals				0	17[3]	Ryan et al., 2004
Wheat[1]	2.9	5.5	48			
Australia: Victoria (17 years; 10 pairs of farms)						
Animals only				0	17[3]	Small and McDonald, 1993
Milk , L/ha/year[2]	6740	9060	26			

[1] Organic wheat was fertilized with 18 kg P/ha/year as rock phosphate and conventional wheat with 16 kg P/ha/year as diammonium phosphate (average grain yields over 3 years from a farm pair where one farm had been under organic management for 30 years).
[2] Conventional pastures received 27 kg P/ha/year as soluble synthetic fertilizers, while biodynamic pastures received no P (average milk yields over 3 years from 10 paired farms where one farm in each pair had been under biodynamic management for an average of 17 years).
[3] N directly applied in fertilizer (N inputs from legumes not calculated).

Australia show that high colonization does not overcome the serious P-deficiency experienced in these systems (Ryan et al., 2000; Ryan and Angus, 2003). Indeed, as the fungi obtain all carbon (C) requirements from the host plant, if the fungi supply no return nutritional benefits they may act as a parasite on crops, reducing crop yield potential (Ryan et al., in press). The generalization that organic practices automatically stimulate an enlarged soil biological community, and that this can partly substitute for inorganic fertilizers, is inaccurate (Ryan and Ash, 1999).

Lower mean N input in organic farming—does it result in less nitrate leaching?

A comprehensive literature review showed that the average leaching of nitrate (NO_3) over a crop rotation was somewhat lower per unit area from organic systems than conventional systems (Kirchmann and Bergström, 2001). However, a correct comparison of leaching between systems also requires yields to be considered and this was not accomplished due to differences in the sequence and type of crops grown, differences in the input intensity

Table 2. Partial N budget in organic and conventional long-term trials in Sweden.

Experiment and farming system	Organic			Conventional			Reference
	Input	Offtake	Leaching	Input	Offtake	Leaching	
	kg N/ha/yr			kg N/ha/yr			
Halland-site							
Crops only	66	30	43	99	79	29	Torstensson et al., 2005
Crops plus animals	120	105	35	113	71	26	
Västergötland-site							
Crops only	105	42	20	113	85	3	Torstensson, 2003a Lindén et al., 1993
Mean	**97**	**59**	**33**	**108**	**78**	**19**	

of nitrogen (N) and a general lack of yield data (Kirchmann and Bergström, 2001). In a series of Swedish long-term field lysimeter trials that commenced in the early 1990s, similar crop rotations in the organic and conventional system were maintained, except in years when green manure was grown. Furthermore, mean N input in the organic systems was close to that of conventional systems (**Table 2**). In these studies, on both a sandy and a clay soil, organic systems had greater nutrient leaching and greater release of N and P to drainage water both per hectare and per unit of harvested N. These experiments indicate that if differences between comparative studies caused by different crop rotations and N input intensity are largely eliminated, leaching of N from organic systems is not lower per unit area.

It appears that the asynchrony of crop N demand and N release from manures compared to inorganic synthetic fertilizers is the major cause for the higher leaching losses from organic systems, as more manure N remains in the soil after application and is mineralized at times when there is no crop demand (Bergström and Kirchmann, 1999; 2004).

Is nutrient cycling enhanced by organic farming?

There is no doubt that the sustainability of most agricultural systems could be improved through an increased emphasis on recycling and greater return of nutrients in municipal wastes and off-farm products. However, losses via the food cycle would not be reduced through widespread adoption of organic farming as current regulations within the organic movement do not allow use of urban wastes due to concerns about contamination with metals and organic pollutants. To improve recycling of nutrients and reduce the risk of contamination with pollutants, new recovery technologies to extract nutrients out of wastewater and biogas residues and other municipal wastes are currently being developed. However, as the new nutrient recovery technologies will produce easily soluble, inorganic products, only conventional farmers may be able to use these products and thereby improve nutrient cycling.

To maintain soil fertility, organic farmers may purchase approved organic fertilizers. In Europe, these fertilizers generally originate from conventional production. In fact, in Sweden there is an increasing trend in organic farming to apply nutrients of off-farm origin via approved organic fertilizers such as meat meal, bone meal, poultry manure, and wastes derived from food industries (Swedish Control Organization for Alternative Crop production). This is an indirect transfer of nutrients originating from conventional production and creates a reliance on production systems fertilized with inorganic fertilizers. A regulation by the European Union (EU) will prohibit the use of conventionally grown fodder in organic animal production after August 2005. On the other hand, there are practically no restrictions on the use of organic fertilizers, such as animal manures,

derived from conventional farms and on by-products from food processing industries (meat meal, blood meal, bone meal, residues from fish industries, canning industries etc). Thus, organic farmers can continue to rely on the import of nutrients from conventional production through purchase of organic manures. This approach obviously would not be sustainable if a large proportion of farms convert to organic production.

Several peer-reviewed papers conclude that organic farming is superior to conventional agriculture. How stringent are comparisons?

There is a tendency when presenting results from comparative studies of organic and conventional farms to assume that any differences occurring between systems are a consequence of the management factors that are inherently dissimilar, namely the exclusion of pesticides and readily soluble inorganic fertilizers on organic farms. Thus, it is assumed that the results are generally representative of organic and conventional systems. However, differences may be caused by management practices that are potentially open to manipulation in a similar manner in each system and/or may vary greatly within one or both.

The following factors should be considered when evaluating comparative studies of systems:

1) The soil fertility status at the start of an experiment will determine the productivity of the system. In fertile soils, initially, smaller yield differences will be detected and both fertilizer and energy efficiency will be in favor of low-input systems.
2) The choice of crops in rotation will determine N leaching. Crops affect N leaching from agricultural soils in several ways: the longevity of the crop, rooting depth, the amount of crop residues and their mineralization potential and the degree of soil tillage.
3) The amount of imported (purchased) nutrients and organic matter need to be equal. To set aside boundary conditions between systems is not scientific proof for the superiority of one system over the other.

Conclusion

When critical scientific analysis is applied to organic farming, the dogma of superiority of organic farming fails. Despite their aim of being more sustainable, organic principles do not provide a better long-term outcome in the search for sufficient food production than conventional ones. We advocate a flexible approach where farming systems are designed to meet specific environmental, economic, and social goals, unencumbered by unscientific, dogmatic constraints (Kirchmann and Thorvaldsson, 2000). BC

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References: Due to space limitations, the reference list is not printed in the original issue. The reference list is available as a PDF file (with the article) at the website: >**www.ppi-ppic.org**<.

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

International Section

Soil Testing: A Proven Diagnostic Tool

By Sam Portch and Mark D. Stauffer

Soil testing is being under-utilized in the developing world, but data show it puts money in farmers' pockets even when the relatively high cost of a complete analysis is considered. Developing the system to truly meet a farmer's needs is both practical and feasible.

It is difficult to determine who exactly began the science of soil testing. Certainly, Europeans such as Justin von Liebig, famed for the Law of the Minimum, and Jean Baptiste Boussingault, sometimes referred to as the father of modern agricultural chemistry, would be candidates as founding fathers. Since then, several scientists during the late 1920s and early 1930s, including those well known by their analytical methods such as Bray, Morgan, Spurway, and Truog, advanced soil testing by showing the importance of measuring labile or available rather than total plant nutrient contents. In terms of service, one of the earliest laboratories established to analyze large numbers of farmers' samples was developed in the early 1940s by J.W. Fitts in Nebraska.

Today, around 4 to 5 million (M) soil samples are analyzed annually in North America alone, in both private and state operated facilities. While this is an impressive number, it still falls short of being adequate for the region's large cultivated area. If one looks outside North America, it is clear that soil testing is even more underutilized as a diagnostic tool. The most frequently noted reasons are discussed within this article along with points to consider for improving its application.

Soil testing at Bathalagoda Research Station in Sri Lanka showed the need for K fertilizer. Application of K fertilizer resulted in 1 t average yield response over three consecutive rice crops.

Common Pitfalls

The first issue is that many laboratories throughout the world routinely offer an incomplete assessment of soil fertility, providing only an analysis of pH, organic matter, some form of nitrogen (N), available phosphorus (P), and potassium (K). Data from China (**Table 1**) illustrate this problem as the prevalence of secondary and micronutrient deficiencies in a number of soils obviously means that a large percentage of soils were not receiving adequate analyses—at least 49% if one considers only zinc (Zn). But given the range of deficiencies, at least 70 to 80% of these soils were inadequately assessed until a complete analysis was done. Unfortunately, the same can be said for research results based on incomplete soil analysis. Based on **Table 1**, greater than 50% of

Table 1. Results of 140 greenhouse trials based on soil analyses with soils from 17 provinces of China (relative dry yield matter with optimum [OPT] as 100 %).

Nutrient omitted from OPT	# soils showing deficiency, % of total 140	Range of relative yield, %	Average relative yield, %
-N	137 (98%)	6.1 to 83.9	45.2
-P	126 (90%)	8.5 to 89.7	39.6
-K	84 (60%)	39.0 to 89.8	73.5
-Ca	20 (14%)	2.2 to89.0	52.8
-Mg	25 (18%)	34 to 89.7	74.7
-S	45 (32%)	14.0 to 89.8	71.3
-Fe	17 (12%)	46 to 87.5	79.4
-B	36 (26%)	65 to 89.7	80.9
-Cu	37 (26%)	40 to 89.5	77.2
-Mn	34 (24%)	50.2 to 89.5	79.1
-Mo	28 (20%)	38.7 to 89.4	79.5
-Zn	68 (49%)	40.0 to 89.6	75.1

research using only N, P, and K analyses would give misleading, lower than optimum yield results.

Incomplete analyses lead to the next reason for under-utilization of soil testing—that being popularization of **generalized, low yielding fertilizer recommendations**. Continued mischaracterization of soil fertility status sets up a feedback loop wherein researchers can only obtain misleading, suboptimal results. The failure of researchers to scrutinize their individual trials sufficiently results in the pooling of poor data with good data. Setting reasonably high yield goals for each trial could help researchers distinguish between good and poor data. Low yielding trials should undergo further study to determine why they performed poorly. If the trial had excessive insect damage, incorrect analysis, poor weather or management, etc., the data should not be pooled with other valid data. Thirdly, years of research and observations by the authors, particularly in developing countries, has led to the conclusion that conservative recommendations—to help the farmer reduce his fertilizer costs—often reduce his income substantially by inefficient utilization of all inputs, including fertilizers. Little or no thought is given to the opportunity cost of under-utilized yield potential.

Three reasons why many generalized fertilizer recommendations result in low yields:

a) Many misleading research results have guided researchers this way;
b) Pooling of poor data with good;
c) An inherent feeling that conservative recommendations save farmers money by reducing fertilizer input costs without looking at lost profit.

Slow service is probably the worst deterrent preventing farmer use of soil testing services. Returning fertilizer recommendations to a farmer long after samples were taken from the field minimizes the benefit, giving the entire concept of soil testing a bad reputation. Recommendations have little meaning to the farmer if the crop for which they were required is already planted (although the soil test results are useful for future nutrient management). Slow service is most apparent in developing countries where a turn-around time of less than one month is exceptional. In countries where two or three crops are grown per year, faster service is essential. A maximum of 7 to 10 days would be acceptable; anything longer detracts from the service.

The last common concern is cost of the service. Subjecting a soil sample to a 'complete' analysis involves 12 to 14 determinations and calculations. The cost of this varies from country to country, but an individual sample would cost between US$12 to US$20, including the report with recommendations. This is often out of range for many resource-

In Tibet, the balanced fertilization plot (at left) showed great response for barley compared to the local recommended practice (at right).

poor farmers, especially those managing a fraction of a hectare. The burden to the farmer could hopefully be lessened through either analyzing a larger volume of soils, thereby reducing the cost per sample or by subsidy made available by government or the ag retailer as part of a customer service package. In the case of small holders, one successful compromise has been to encourage adjoining farmers to consolidate their fields and develop a shared recommendation of fields with similar landscape, soil type, crop, management, and yield goals. Farmer cooperatives might develop a seasonal field sampling rotation that produces a common recommendation for a small number of fields. Thus, analysis cost can be spread amongst a large number of farmers, but still have an applicable area.

Some may say soil testing is not a worthwhile endeavor, particularly in developing countries. However, the potential benefits from more definitive research results and recommendations require that one must look for ways to develop sound soil testing systems. How could this be done?

The first goal should be increased awareness (from administration to technician-level) about the problems mentioned. Strategies to overcome these problems will no doubt follow. The main objective is to regard soil testing as more than just the 'bricks and mortar' of a laboratory. A complete program provides: sampling and sample handling, the laboratory, local research and data interpretation, dynamic recommendations, plus education and extension in all the above.

Benefits from an Optimized Soil Testing Service

Where reliable soil testing is being used, many successful and profitable research- and farmer-oriented results are produced. One of the most recent and convincing examples comes out of the Bathalagoda rice research station in Sri Lanka. Prior to intervention, six consecutive seasons of N, P, and K research on rice failed to show any need for K fertilizer. Secondary and micronutrient deficiencies were not being addressed, hence, only low yields were obtained. After a complete soil test, magnesium (Mg), sulfur (S), boron (B), and copper (Cu) were included in all treatments along with variable rates of N, P, and K. The result was a 1 tonne (t) average yield response to K over three consecutive rice crops. Seasonal yields ranged between 5.3 and 6.2 t/ha when all yield-limiting nutrients were applied. Higher yields are almost certainly possible using this knowledge to adjust other agronomic practices.

Many observations in India show higher, more profitable yields when fertilizer programs are based on complete soil analyses. Data often illustrate that recommendations made by many of the state scientists are too conservative. In northern India, highly significant yield increases in pea (450 kg/ha) and chickpea (1,390 kg/ha) were obtained when soil test-based treatments were compared to generalized state recommendations (**Table 2**). Significant responses to P and K were obtained with both crops (data not shown) and, in both crops, further additions of S and Zn greatly increased yield over treatments supplying only N, P, and K. The

influence of manganese (Mn) and B (data not shown) were also positive in both cases, but only statistically significant in the pea crop.

Farmers at five locations in eastern India used soil test-based fertilizer recommendations to produce more profitable rice crops (**Table 3**). Interestingly, the average loss was less when farmers used their own fertilizer program instead of the state recommendation, but both were far less profitable than soil test-based recommendations.

Table 2. The effect of different fertilizer treatments on selected treatments in trials with pea and chickpea in northern India.

Crop	Treatment	Grain yield, kg/ha	Straw yield, kg/ha
Pea	$N_{30}\ P_{90}\ K_{90}\ S_{40}\ Zn_{20}\ Mn_{10}\ B_5$	3,200	4,470
	State recommendation	2,750	3,870
	$N_{30}\ P_{90}\ K_{90}\ S_0\ Zn_{20}\ Mn_{10}\ B_5$	2,900	4,000
	$N_{30}\ P_{90}\ K_{90}\ S_{40}\ Zn_0\ Mn_{10}\ B_5$	2,920	4,020
	$N_{30}\ P_{90}\ K_{90}\ S_{40}\ Zn_{20}\ Mn_0\ B_5$	3,000	4,170
	C.D. 5%	*137*	*182*
Chickpea	$N_{30}\ P_{90}\ K_{90}\ S_{40}\ Zn_{20}\ Mn_{10}\ B_5$	3,390	4,770
	State recommendation	2,000	2,800
	$N_{30}\ P_{90}\ K_{90}\ S_0\ Zn_{20}\ Mn_{10}\ B_5$	2,800	3,930
	$N_{30}\ P_{90}\ K_{90}\ S_{40}\ Zn_0\ Mn_{10}\ B_5$	2,900	4,100
	$N_{30}\ P_{90}\ K_{90}\ S_{40}\ Zn_{20}\ Mn_0\ B_5$	3,180	4,450
	C.D. 5%	*463*	*653*

C.D.=Critical difference

In the highlands of Tibet, research trials with barley and wheat showed significantly higher yields using soil test-based recommendations compared with present farmer practice. Yield increases were 1,733 kg/ha with barley and 493 kg/ha with wheat. These gains provided extra farmer profit of US$313 and US$83/ha, respectively. Two unreplicated demonstration trials with the same crops in nearby locations produced similar results.

Table 3. Loss of profit (US$) growing rice when state recommendations (SR) and farmer's practice (FP) were compared with soil test-based fertilizer recommendations in eastern India.

Location	Loss with SR	Loss with FP
1	-57.70	-53.15
2	-54.20	-
3	-65.40	-52.25
4	-55.75	-69.50
5	-47.00	-37.20
Average	-56.00	-53.00

Throughout Asia, networks of unreplicated, multi-located field demonstrations provide an effective means of showing farmers that soil test-based recommendations are more profitable than either state recommendations or their own current practices. Most results remain unpublished despite their influence on common practice. For example, the average cost of fertilizer for the soil test-based treatment for mustard in eastern India was US$84/ha…higher than the state recommendation (US$43/ha) or the farmer practice (US$59/ha)…but the increased profit resulting from its application was US$183 over the state recommendation and US$149 over the farmer practice (**Table 4**). Conservative recommendations clearly do not help farmer profitability.

Results from two pomelo demonstration trials in the Fujian Province of China showed soil test-based yields averaged 7 t/ha over the current farmer practice and was US$870/ha more profitable. In two banana demonstration trials in the same province, an average increased profit of US$540/ha was obtained using the soil test-based recommendations compared with current farmer practice. Similar comparisons with citrus at three locations in Hubei Province increased farmer

Table 4. Mean values of fertilizer costs and farmer profit comparing soil test (ST) based recommendations with state recommendations (SR) and farmer practice (FP) in five field demonstrations with mustard in eastern India.

	Cost of fertilizer, US$/ha			Profit, US$/ha	
	ST	SR	FP	ST over SR	ST over FP
Mean values	83.80	41.70	59.00	183.00	149.10

profit by an average US$360/ha. Many provinces in China, states in India, and other countries of Asia need to revise their fertilizer recommendations based on complete soil testing information.

Summary

Considering data in this article are derived from research and demonstration trials conducted in temperate to tropical conditions with a wide variety of crops, it should be apparent that soil testing, when done correctly, is key to judicious fertilizer use and maximum economic yield. However, useful results are obtained only when the whole soil testing program operates at a high level of speed, control, and precision while performing a complete analysis.

Testing soil has a cost. However, this should be considered as part of the cost of production of a crop or cropping sequence. If done for the examples used in this article, even using the higher estimate for analysis cost, all results still remain quite profitable for the farmer. Considering one soil test may be useful for two or three seasons...depending on the cropping pattern...the value of the recommendation will increase as the cost of analysis can be spread over several crops. In perennial crops, benefits from proper soil and plant analysis can be realized over several years, making the investment both minimal and wise.

There is also a hidden benefit to soil testing. Following soil test-based recommendations usually improves fertilizer use efficiency, meaning more of the applied fertilizer is taken up by the growing crop to produce higher yields. Higher yields also produce more organic matter to be returned to the soil, while losses of applied N to the environment are reduced, which is important for water and air quality. Considering all its benefits, correct soil testing should be vigorously promoted and utilized throughout the agricultural world. BC

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Acknowledgments

The authors wish to sincerely thank Drs. K.N. Tiwari, Kaushik Majumdar, Chen Fang, Tu Shihua, and Darshani Kumaragamage, as well as their cooperators who provided the PPI/PPIC funded data cited in this article.

Soil analyses (Sam Portch and Arvel Hunter, 2002) were provided by the Chinese Academy of Agricultural Sciences (CAAS)/PPIC laboratory located in Beijing and Agro Services International in Florida, USA.

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Portch, Sam, and Arvel Hunter. 2002. A Systematic Approach to Soil Fertility Evaluation and Improvement. PPI/PPIC China Program Special Pub. No. 5.

Note: The publication *A Systematic Approach to Soil Fertility Evaluation and Improvement* is available on request. Contact the PPIC office in Saskatoon, Saskatchewan; telephone (306) 652-3535, fax (306) 664-8941, e-mail: gsulewski@ppi-ppic.org.

Fertilizers to Sustain Production of 100 Million Metric Tons of Grain

By F.O. García, G. Oliverio, F. Segovia, and G. López

Argentina is anticipating a large increase in its grain production potential. It is clear that improved soil nutrient balance is a key to sustaining this goal.

Sustainable productivity in our agricultural ecosystems is an important objective for the 21st century. Sufficient attention to crop and soil management details such as control of weeds, insects, diseases, and soil erosion, along with adequate crop rotation, soil organic matter balance, and nutrient supply are critical components of sustainability. Adequate crop nutrient supply is possible only in soils of optimum fertility. Most of the grain production regions of Argentina...the Pampas and the extra-Pampas areas...were developed under high native soil fertility. However, negative soil nutrient balances (nutrient removal exceeding nutrient application) during 100 years of cropping history have resulted in general deterioration of fertility levels (Andriulo et al., 1996; García, 2001). Sustained, high yield agricultural production can be assured once these negative balances are addressed. Crop fertilization is the main tool available.

Nitrogen (N), phosphorus (P), and in recent years, sulfur (S) are the nutrients of most concern in the Pampas and other grain-production regions. Deficiencies and responses to other nutrients such as potassium (K), magnesium (Mg), and micronutrients are reported for specific crops and areas. Grain production in Argentina, especially for soybeans, has sharply increased in the last decade (**Figure 1**). A report from Fundación Producir Conservando has projected a potential production of 100 million metric tons (M t) of grain for 2010/11 (Oliverio and López, 2002). This increase is projected from further expansion of planted area as well as average yield improvements for the major grain crops.

This article summarizes and discusses the results of a subsequent projection by Fundación Producir Conservando (Olivero et al., 2004), which estimates fertilizer consumption based on improved soil nutrient balances for the goal of 100 M t grain production. The full report is available at >www.producirconservando.org.ar<.

Fertilizer consumption in Argentina has steadily increased since the early 1990s at a rate of 146,000 t/year (**Figure 2**). Despite this trend, the overall nutrient balance is still very negative (**Figure 3a**). In the four major grain crops, removal to application ratios for N, P, K, and S are heavily weighted toward depletion at: 3 to 5, 2 to 2.5, 50 to 100, and 10 to 100, respectively. The 2010/11 projection by Olivero et al. considers a set of improved rates of replenishment for soil N, P, and S removed by soybean, wheat, corn, and sunflower. These replenishment rates were established for each county, or department, according to present soil nutrient availability. In highly fertile soils, the replenishment rates were usually lower than 100%, allowing for a decrease in soil nutrient availability

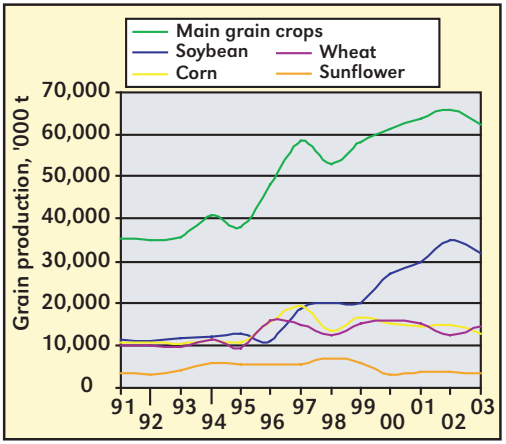

Figure1. Evolution of corn, wheat, soybean, and sunflower production in Argentina, 1991-2003. Source: SAGPyA.

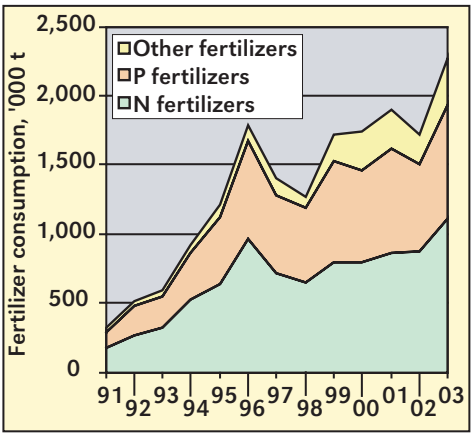

Figure 2. Evolution of consumption of N, P, and other fertilizers in Argentina, 1991-2003. Adapted from data of SAGPyA and Fundación Producir Conservando.

from a negative nutrient balance. In all cases, crop- and county-specific replenishment rates were set higher than current estimates. Phosphorus replenishment rates were set above 100% for wheat and corn in order to account for P removed by double-cropped soybeans, a portion of the rotation that traditionally relies on residual soil P.

Table 1 provides site-specific examples of the nutrient replenishment rates used in the projection. **Table 2** shows national averages for main grain crops in 2002/03 and those projected for 2010/11.

As a result of the projections, total fertilizer consumption estimated at 2.3 M t in 2003 would increase by 120% to almost 5.1 M t by 2011. Cereal and oil crops would account for 4 M t, whereas other crops (fruits, vegetables, forages, and others) would account for 1.1 M t. The estimation by Olivero et al. considered only increases for N, P, and S. Thus, if

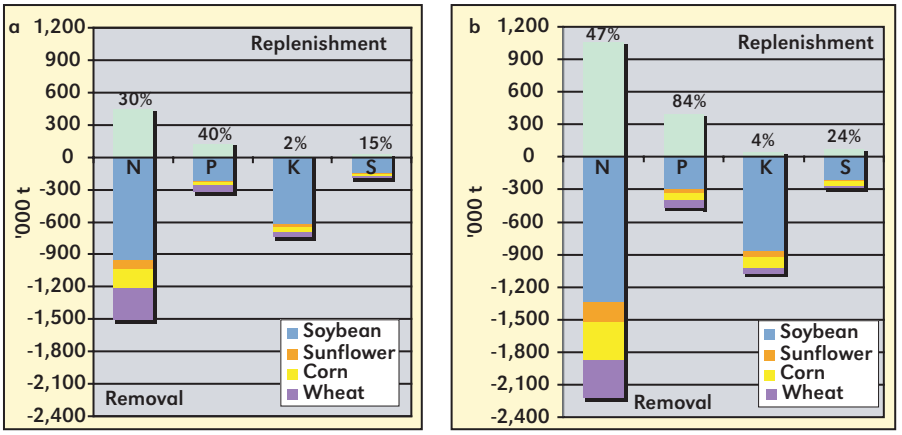

Figure 3. Nutrient removal and replenishment in the four major grain crops of Argentina estimated for the 2003/04 season (a) and projected for the 2010/11 season (b). The estimate for N removed by soybeans was reduced by 50% considering N supplied by biological N fixation. Adapted from data of SAGPyA and Fundación Producir Conservando.

the potential increase for K fertilizer consumption is also included, fertilizer consumption by 2011 would equal 5.3 M t. Based on the proposed nutrient replenishment rates, a marked improvement in the removal to application ratios is expected , with values equal to: 2.1, 1.2, 22.8, and 4.2 for N, P, K, and S, respectively (**Figure 3b**).

Table 1. Percentage of replenishment of N, P, and S used to estimate potential nutrient needs in some counties of Argentina (Oliverio et al., 2004).

		Replenishment, %		
County/Department	Province	N	P	S
Bahía Blanca	Buenos Aires	75	100	60
Cap. Sarmiento	Buenos Aires	88	100	60
Gral. Alvarado	Buenos Aires	63	100	40
Gualeguay	Entre Ríos	88	100	40
Marcos Juarez	Córdoba	88	100	60
25 de Mayo	Buenos Aires	75	100	60
Venado Tuerto	Santa Fe	88	100	60

Most of the increase would be attributed to P fertilizers. Since soybeans will continue as the main crop, future increases in N application would be much less pronounced compared to P. The expansion of soybean monoculture raises concern not only because of the deficit in soil N replacement, but also because of low carbon (C) inputs (i.e. organic matter) to the soil. Grasses as cover crops and a higher proportion of corn and wheat in the rotation would increase N fertilizer demand, but could also help to improve soil C and N balances. Crop-pasture rotations, historically the main rotation in the Pampas, are another possibility to improve soil organic matter balances and soil C and N.

Table 2. Percentage of replenishment of N, P, and S in corn, soybean, sunflower, and wheat estimated for 2002/03 and projected for 2010/11 (Oliverio et al., 2004).

		Replenishment, %		
Crop	Year	N	P	S
Corn	2002/03	55	103	3
	2010/11	74	138	25
Soybean	2002/03	0	19	5
	2010/11	0	54	24
Sunflower	2002/03	4	37	3
	2010/11	99	100	25
Wheat	2002/03	77	190	0
	2010/11	77	190	25

Field research has provided strong support for the adoption of balanced fertilization programs, not only because of the agronomic and economic results, but also because of the possibility of providing a better soil nutrient balance. Besides general responses to N, P, and S, responses to other nutrients such as boron (B), chloride (Cl), and zinc (Zn) have been reported. BC

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New Leaf Color Chart for Effective Nitrogen Management in Rice

By C. Witt, J.M.C.A. Pasuquin, R. Mutters, and R.J. Buresh

Leaf color charts (LCC) offer substantial opportunities for farmers to estimate plant nitrogen (N) demand in real time for efficient fertilizer use and high rice yields. We developed a new, standardized LCC for rice in Asia based on the actual colors of rice leaves. The new chart and updated guidelines for its use are promoted in many Asian countries through the Irrigated Rice Research Consortium (IRRC).

Asian farmers generally apply fertilizer N in several split applications, but the number of splits, amount of N applied per split, and the time of applications vary substantially. The apparent flexibility of rice farmers in adjusting the time and amount of fertilizer application offers potential to synchronize N application with the real-time demand of the rice crop.

Improved N management and balanced fertilization are key components of the site-specific nutrient management (SSNM) approach developed by the International Rice Research Institute (IRRI) in partnership with the National Agricultural Research and Extension Systems in Asia. Field studies in major irrigated rice areas have shown significant yield and profit increases with SSNM over typical farmer fertilizer practice (Dobermann et al., 2004). These studies revealed that sub-optimal N management by farmers is a key constraint to increasing yield (**Figure 1**). Improved N management caused greater yield responses to fertilizer N application compared to farmer practice, and yield responses to fertilizer phosphorus (P) and potassium (K) application often only occurred after yields increased through improved N management with SSNM. Leaf color charts are an effective, low-cost tool that can assist farmers in improving their N management, and efforts are underway to promote the technology at wider scale among Asian rice farmers.

Numerous LCC units have been fabricated and distributed to farmers in a number of Asian countries since the 1990s. The most widely used LCC was developed by IRRI in collaboration with

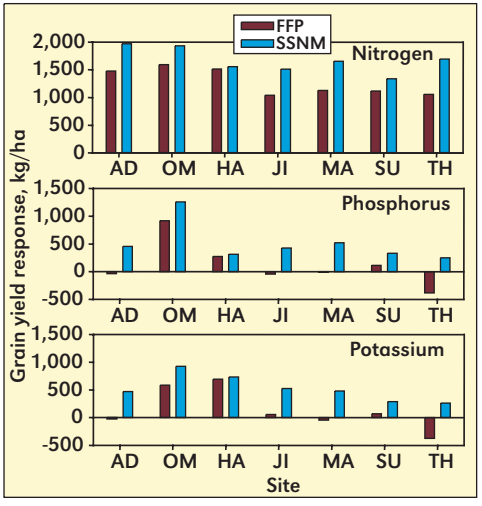


Figure 1. Yield response to fertilizer N, P, and K application following farmer fertilizer practice (FFP) and the SSNM approach on 179 farms at seven key sites with irrigated rice in Asia, 1997-1999. AD = Aduthurai (Tamil Nadu, India), OM = Omon (Cantho, Vietnam), HA = Hanoi (Vietnam), JI = Jinhua (Zhejiang, China), MA = Maligaya (Nueva Ecija, Philippines), SU = Sukamandi (West Java, Indonesia), TH = Thanjavur (Tamil Nadu, India).

Figure 2. The leaf color chart developed by University of California Cooperative Extension (UCCE) for rice in California.

the Philippine Rice Research Institute (Balasubramanian et al., 1998). Fueled by the success of the chart and an increasing demand for quality and low-cost LCCs in Asia, we used an approach developed at the University of California Cooperative Extension (UCCE) to improve and standardize the colors of the LCC. In this approach, a meaningful range of green plastic chips ranging from yellowish green to dark green match the color range of rice leaves that cover a continuum from leaf N deficiency to excessive leaf N content. This approach was first used to develop an LCC for California rice varieties (**Figure 2**). A systematic analysis using a Minolta CM 3700-d spectrophotometer showed that the colors of LCCs available in Asia do not match those of rice leaves (Witt and Pasuquin, unpublished).

We used actual leaf spectral reflectance measurements from a 2-season field experiment in 2001 involving 10 modern rice varieties grown at three different N levels to develop target reflectance patterns for an ideal LCC prototype (Witt et al., 2004). A spectral reflectance pattern describes the composition of light that is reflected from a rice leaf across the whole spectrum of wavelength from blue (400 nm), over green (550 nm) to infrared (700 nm). Based on the target pattern (**Figure 3A**), we worked with the local pigment and plastic industries in the Philippines and produced a standardized chart that captures the relevant range of rice leaf colors in Asia. The new 4-panel LCC is shown in **Figure 4**. We chose only 4 color panels for the LCC because any color outside this range would not be a desirable goal for modern, high yielding varieties in Asia as it would either be a sign of extreme N deficiency or excess supply of N.

The quality of the new 4-panel LCC was evaluated using spectral reflectance (SR) measurements (**Figure 3**). In this analysis, we compared SR patterns of rice and maize leaves with those

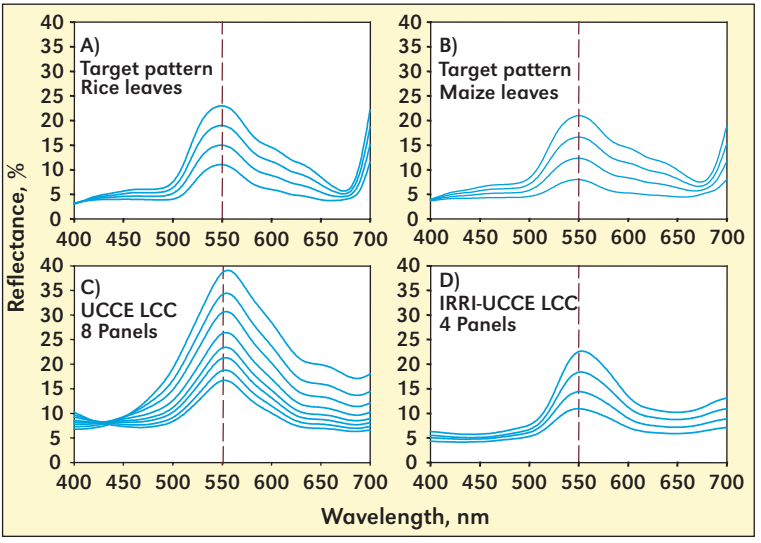


Figure 3. Target spectral reflectance patterns for a theoretical LCC based on actual reflectance measurements performed on leaves of major Asian rice varieties (A) and of a maize variety (B). Actual reflectance patterns for LCCs developed by UCCE for Californian rice varieties (C) and IRRI-UCCE for Asian rice varieties (D). The dotted line at 550 nm (green) reflects the maximum reflectance of actual rice and maize leaves in the visible spectrum. The top line in each chart represents the lightest green, while the lowest line represents the darkest green.

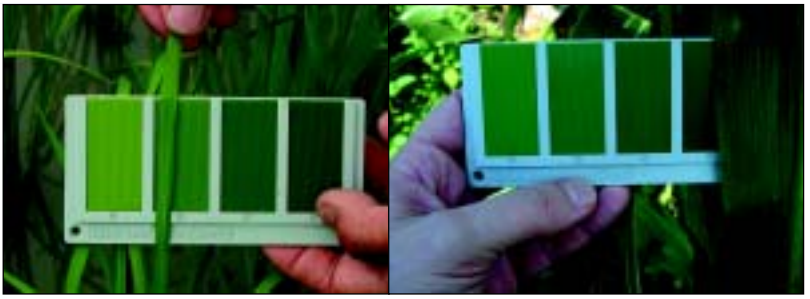
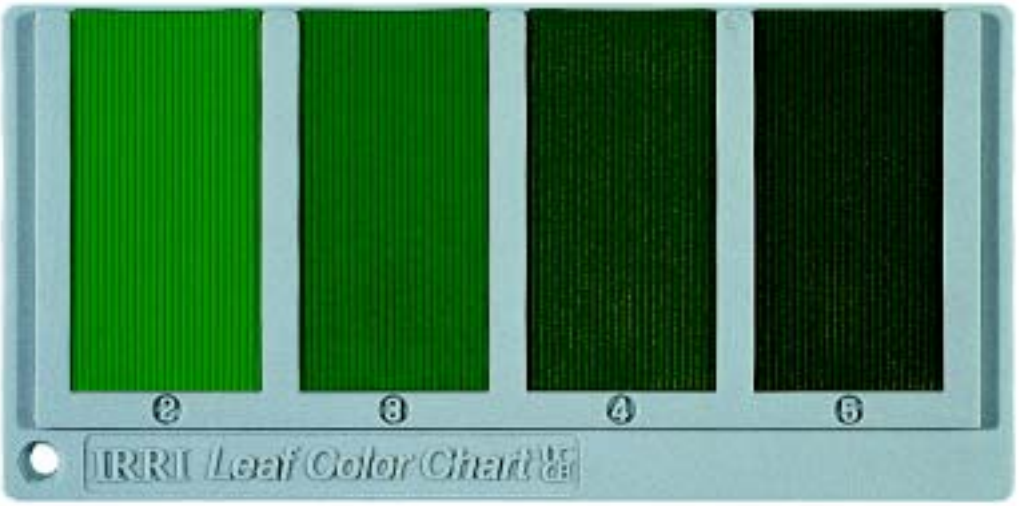


Figure 4. The new 4-panel LCC developed by IRRI in collaboration with UCCE for rice (left). The same chart might also be a useful tool in maize (right).

of the two leaf color charts developed by UCCE and IRRI. Recognizing technical limitations in plastic manufacturing, the two LCCs achieved a respectable match with actual SR patterns of rice and maize leaves (**Figure 3CD vs 3AB**). Typical SR patterns of rice and maize leaves were similar (**Figure 3AB**) with greatest reflectance and sensitivity at 550 nm (green). Leaves with different N content would, therefore, differ greatly at this bandwidth, while differences in reflectance decrease towards both ends of the spectrum. Color panels of both charts had their greatest reflectance at 550 nm so that this condition was met. Further, the plastic panels showed equidistant reflectance among color panels at 550 nm (**Figure 3CD**), which means that the change in color was consistent from panel to panel. This confirmed the visual impression that colors of neighboring panels can be easily distinguished in both charts (**Figure 2 and 4**). The comparison shown in **Figure 3** also indicated that the new 4-panel chart may be more suitable for rice varieties in Asia compared to the LCC that was developed for rice varieties in California.

The new 4-panel LCC can be used for all modern, high yielding rice varieties in Asia, but guidelines on the use of the chart have to be adjusted to local conditions. Major progress has been made in recent years in the on-farm evaluation of LCC for effective N management and the general guidelines on its use are provided in greater detail elsewhere (Fairhurst and Witt, 2002). Briefly, a critical leaf color has to be maintained for optimal growth and the LCC provides guidance when to apply fertilizer N to avoid N deficiency. The critical leaf color depends on varietal group (inbred, hybrid, new plant type) and crop establishment method (planting density). There are two major approaches in the use of the LCC. The *fixed splitting pattern* approach provides a recommendation for the total N fertilizer requirement (kg/ha) and a plan for splitting and timing of applications in accordance with crop growth stage, cropping season, variety used, and crop establishment method. The LCC is used at critical growth stages to decide whether the recommended standard N rate would need to be adjusted up or down based on leaf color. In the *real-time* approach, a prescribed amount of fertilizer N is applied whenever the color of rice leaves falls below the critical LCC value. The critical value might fall between two existing panels of the LCC, but guidelines can be adjusted so that the color panels of the LCC will not have to be changed. Local guidelines on the LCC use have now been developed for the major irrigated rice domains in Asia.

Since its introduction in December 2003, more than 250,000 units of the 4-panel LCC have been produced and will be distributed to Asian rice farmers in Bangladesh, China, India, Indonesia, Myanmar, the



This is the actual size of the new 4-panel LCC.

Philippines, Thailand, and Vietnam. Research is underway to evaluate the suitability of the LCC for N management in maize in a joint collaborative project between the Indonesian Agency for Agricultural Research and Development and the PPI/PPIC-IPI Southeast Asia Program. BC

Note: For availability and guidelines on the use of the LCC in rice, please contact Dr. R.G. Mutters (UCCE chart) or Dr. R.J. Buresh (IRRI-UCCE chart).

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Acknowledgments

The International Rice Research Institute (IRRI), the Swiss Agency for Development and Cooperation (SDC), PPI/PPIC, and the International Potash Institute (IPI) provided funding for this research.

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Potash & Phosphate Institute: Still Going Strong At 70

When PPI observed its 50-year milestone back in 1985, several events focused on the remarkable achievements of this science-based nutrient management organization. A symposium in Atlanta drew leading scientists, industry personnel, and others from around the world. Speakers presented papers dealing with all aspects of **K**, from mining and distribution to the technical physiological aspects of **K** utilization in plants—and everything in between. The highly acclaimed book *Potassium for Agriculture* was published by the American Society of Agronomy and introduced at that event. Also, a special issue of *Better Crops with Plant Food* highlighted the history of the Institute, beginning with its founding in Washington, DC, back in 1935.

In April of this year, the Institute will be 70 years old. There are no special celebrations planned. That's to be expected, since 70 is one of those in-between years, not as impressive as 50 or 65 or 75. Yet, this is a special year at PPI because it marks the continuing support of the Institute's member companies, producers of **P** and **K**. Having been a part of the Institute family for more than 30 years, I have long since recognized the uniqueness of the industry support which the Institute has enjoyed (and earned) during the past 70 years.

The financial commitment of PPI members to the Institute, with its Ph.D. level scientists and support staff strategically located around the world, is significant. It is critical that such support be steady and long-term. Otherwise, the internationally respected professionals working at PPI could not be attracted to and would not remain with the organization, research and education programs could not be sustained, and the scientific approach to market development could not endure.

The fact that industry supports the scientific approach to advancing appropriate P and K use is a reflection of the vision of industry leaders, a vision that has spanned seven decades and continues today. Through good times and bad, PPI's members have stood their ground and held tightly to the ideals of sound science and integrity in developing the global markets for their products. **So, I wish a happy 70th birthday to PPI and offer a special thanks to the Institute's members for 70 years of progress and steadfast support of the vision that created and continues to carry this wonderful organization—the Potash & Phosphate Institute.**

BETTER CROPS
WITH PLANT FOOD
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