BETTER CROPS
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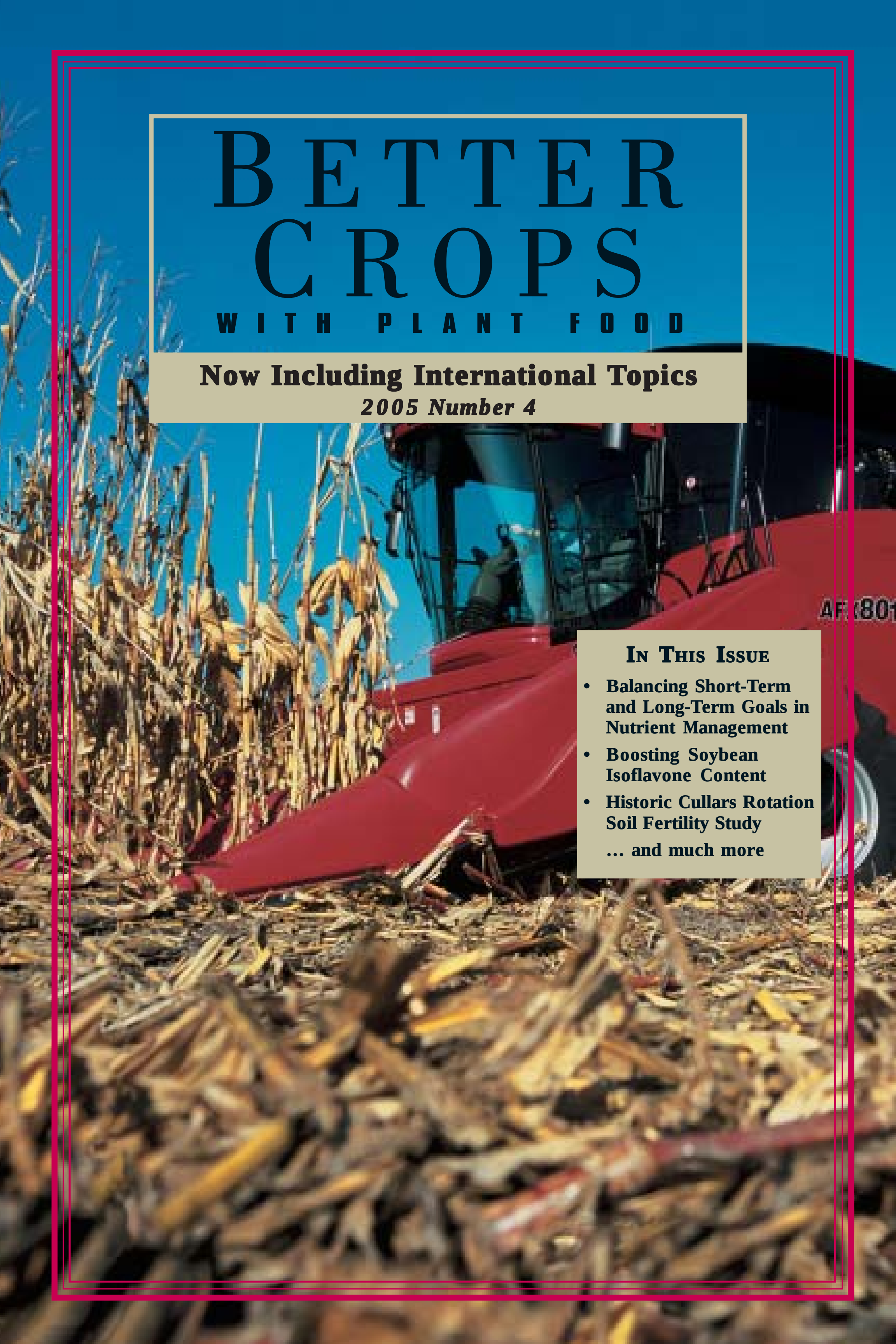
2005 Number 4



In This Issue

- Balancing Short-Term and Long-Term Goals in Nutrient Management
- Boosting Soybean Isoflavone Content
- Historic Cullars Rotation Soil Fertility Study

… and much more

BETTER CROPS
WITH PLANT FOOD

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CONTENTS

PPI/FAR Research Database

At the end of some articles in each issue of *Better Crops with Plant Food*, a line such as "PPI/FAR Research Project SK-35" will appear. This indicates that the article is based at least in part on research supported by PPI and FAR. To find out more about the topic, readers may visit the Research Database at the website: **<www.ppi-far.org/research>**.

The icon shown here is a handy signpost to help you learn more about the various projects, including full annual reports and other publications. The Research Database contains much more detail than can be included in a typical article in this publication.

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David W. Dibb, President of Potash & Phosphate Institute, to Retire

The Potash & Phosphate Institute (PPI) announced in August that Dr. David W. Dibb, President, will retire from the international agricultural research organization at the end of this year. Dr. Dibb's retirement will bring to a close a 30-year career at PPI, including 17 years as President, the longest tenure in that leadership role in PPI's 70-year history.

"It's no overstatement that the world owes a debt of gratitude to David Dibb, who for the past three decades has assisted numerous countries in developing their food production systems," said Bill Doyle, Chairman of PPI's Board of Directors and President and CEO of PotashCorp. "By combining sound, science-based agronomic and economic practices with PPI's unparalleled soil fertility research, Dr. Dibb has touched the lives of millions. The PPI Board and all who know David wish him and his wife, Vivian, a long and healthy retirement. He will be greatly missed."

Raised on a mixed crop and dairy farm in Utah, Dr. Dibb earned his B.S. degree in Agronomy-Soils from Brigham Young University in 1970 and his Ph.D. from the University of Illinois in 1974. As President of PPI, Dr. Dibb has directed the activities of nearly 30 Ph.D. level agronomists in North America and international programs.

Under his leadership, PPI has played a key role in delivering new food production technology to North America, Central America, South America, India, China, and areas in Southeast Asia. He has also directed the establishment of new PPI programs in Northern Latin America, Mexico, Central America, Latin America Southern Cone, and India.

As President of PPI, Dr. Dibb... working with member companies and the Board of Directors...guided the Institute through a time of significant change in agriculture and in the fertilizer industry.

"PPI/PPIC programs have introduced and encouraged many concepts, technologies, programs, and partnerships that are essential to modern production agriculture. While ideas have been the catalyst, cooperation has been the key to innovative adoption," Dr. Dibb emphasizes.

Among important initiatives, practices, and programs the Institute has encouraged, he lists the following: soil testing; plant analysis; field diagnostics; maximum yield research (MYR) and maximum economic yield (MEY) management; nutrient balance; nutrient uptake and removal, nutrient budgets, and soil test survey summaries; precision agriculture, GPS, and GIS technologies; the International Certified Crop Adviser (CCA) program; site-specific nutrient management; conservation tillage; environmental issues; nutraceuticals, phytochemicals, and food quality; and improvement of food quality through nutrient management.

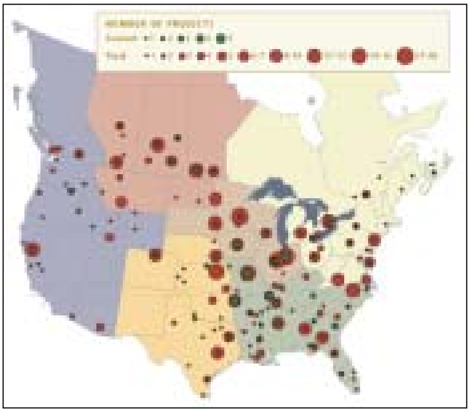
A Fellow of the American Society of Agronomy (ASA), Soil Science Society of America, and American Association for the Advancement of Science, Dr. Dibb is listed in Who's Who in Science and Engineering and Who's Who in America. He has been recognized with the Honored Alumni Award by Brigham Young University's College of Biology and Agriculture, and received the Agronomic Industry Award from ASA. He is also Honorary Professor of the Chinese Academy of Agricultural Sciences. BC

Foundation for Agronomic Research Marks 25 Years of Progress

In 1980, the U.S. hockey team won the gold medal in the Olympics…Post-It Notes were introduced…and the first all news cable network was launched. That year also saw the beginning of the Foundation for Agronomic Research (FAR), established by the PPI Board of Directors. In the 25 years since then, FAR has greatly broadened the scope of agronomic research and education through support of contributors and funding beyond potash and phosphate producers. The in-kind contribution of PPI/PPIC staff time in North America is a key to monitoring various research projects and maintaining communication with researchers.

The Foundation facilitates agronomic research and education programs in crop and soil management by developing cooperative teams among universities and between universities and industry to address specific needs, then finding teams of supporters to provide the necessary funding. FAR has helped launch and sustain research projects on the cutting edge of technology, helped maintain long-term studies to protect important data series, and helped find matching funds from a variety of sources to sustain and expand research programs.

"As traditional funding sources for research programs has continued to decline, FAR is one of the few sources that has maintained a major program in applied and on-farm studies that are vital to modern production agriculture," says Dr. Harold F. Reetz, President of FAR, located at Monticello, Illinois. Some current important initiatives of the Foundation include: high yield systems, best management practices (BMPs) for nutrient management, technology for fertilizer placement, and nutrients and plant health.



This map illustrates distribution of current and total research projects supported by FAR since 1980.

Recently, more than 20 new contributors have joined in supporting FAR programs. A new DVD, "Facilitating the Future of Agronomy", is helping heighten awareness of FAR.

FAR has now been awarded a 3-year Conservation Innovation Grant (CIG) from USDA-NRCS which will be used to develop a series of Fertilizer Best Management Practice Guidelines for six different cropping systems, along with other resources to promote implementation.

In its 25-year history, FAR has supported hundreds of projects on a wide range of crops, soil types, and geographic regions. The map above shows a distribution of projects across North America. Information on current and completed projects can be found in the Research Database on the FAR websites:

RESEARCH DATABASE

>www.ppi-far.org<
>www.FARmresearch.com< BC

Cullars Rotation: The South's Oldest Continuous Soil Fertility Experiment

By Charles C. Mitchell, Dennis Delaney, and Kipling S. Balkcom

Long-term fertility research with major crop rotations provides valuable nutrient management information in addressing sustainable production. The South's oldest fertility experiment is located in Auburn, Alabama. It continues to illustrate the benefits of balanced plant nutrition and fertilizing for the needs of the crop rotation.

Alabama's "Cullars Rotation" experiment (established in 1911) was placed on the National Register of Historical Places in 2003 as the oldest continuous soil fertility experiment in the South. Along with its nearby predecessor on the National Register, "The Old Rotation," which started in 1896, these experiments contain the oldest cotton research plots in the world. Both are located on the campus of Auburn University in east-central Alabama.

Treatments on the Cullars Rotation dramatically demonstrate the long-term effects of fertilization and the lack of specific nutrients on non-irrigated crop yields over a 95-year period. The Cullars Rotation is one of the few sites where controlled nutrient deficiencies can be observed on five different crops during the course of a year (cotton, crimson clover, corn, wheat, and soybean). The experiment preserves a site for monitoring nutrient accumulation and loss and soil quality changes and their effects on long-term sustainability of an intensive crop rotation system.

Agronomics and Experimental Design

The Cullars Rotation (website: http://www.ag.auburn.edu/agronomy/cullars.htm) was designed primarily to study the long-term effect of potassium (K) fertilization, lime, and other nutrients on a 3-year rotation which included cotton, corn, small grain, and summer legumes (cowpeas or soybeans). Research

View of experiment looking toward the east with plots A, B, and C on the right.

on this site led to the discovery of K deficiency in cotton, which had been referred to earlier as "cotton rust" (Atkinson, 1891, 1892). Today, the experiment is a 3-year rotation of: 1) cotton followed by crimson clover, 2) corn harvested for grain and followed by winter wheat, and 3) soybeans double-cropped after the small grain is harvested. The soil is a Marvyn loamy sand (fine-loamy, siliceous, thermic Typic Kanhapludults) in the Coastal Plain physiographic region.

Treatments and plot layout. The study included 11 soil treatments with three crops in the 3-year rotation. In 1914, an additional three treatments (designated A, B, and C) were added to include the effect of winter legumes in the rotation. Plot size is 20 x 99 ft., with a 2-ft. border between each plot and 20 ft. between each tier (block).

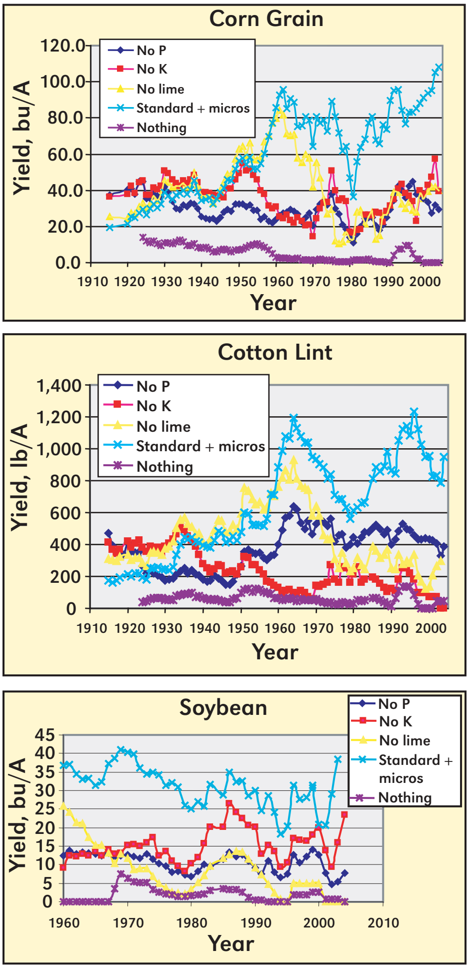


Figure 1. Long-term yield trends on selected treatments for cotton, corn grain, and soybean on the Cullars Rotation, 1911-2004. Each point is a 5-year running average. (Standard + micros is "Plot 10" in **Table 2**)

Tillage and other cultural practices. All crops were conventionally tilled with moldboard plowing, disking, and regular cultivation until 1997, and all crops have been grown with minimum tillage and transgenic cultivars since. Cotton and corn are planted directly into previous crop residue in narrow rows (30-in. rows) after paratilling or in-row subsoiling. Soybeans are drilled into wheat residue in June using a no-till drill. Since 1996, few insecticides have been applied for insect control, primarily because of the cotton boll weevil eradication program and the advent of Bollgard® technology. All crops are machine-harvested, although cotton and corn yield estimates are made by hand-harvesting portions of each plot.

Fertilization. In the early years of the Cullars Rotation, sources of plant nutrients were blood meal for nitrogen (N), superphosphate (0-18-0) and rock phosphate for phosphorus (P), and kainit (0-0-12) for K. In the last few years, P as concentrated superphosphate (0-46-0), K as muriate of potash (0-0-60), sulfur (S) as gypsum, and a micronutrient mix containing boron (B), zinc (Zn), manganese (Mn), copper (Cu), and iron (Fe) have been applied to the designated treatment plots in split applications in the spring prior to planting cotton and in the fall just prior to planting small grain. Nitrogen as ammonium nitrate (34-0-0) is applied to designated plots just prior to planting cotton and corn and as a side-dress application. The small grain is top-dressed with 60 lb N/A in late February. Fertility treatments and recent soil test results are presented in **Table 1**.

The Yield Record

Few research areas exist in the U.S. where one can see such dramatic deficiencies of plant nutrients on one site. Particularly dramatic are the plots where no soil amendment has been applied since 1911 (treatment C), the "no K" plots (treatment 6), the "no lime" plots (treatment 8), and the "no P" plots (treatment 2). Deficiencies sometimes appear on the other treatments, but are less dramatic. In general, cotton is most sensitive to low soil K in this experiment while corn, soybean, and small grain are most sensitive to low soil P (**Table 2**). Cotton and soybean seem to be more sensitive to the acid soil (pH=4.7 in 2004) in the no lime treatment than other crops in the rotation. All plots except treatment 8 (no lime) and treatment C (nothing) receive an application of ground, dolomitic limestone whenever the surface soil pH

Table 1. Treatments and mean soil pH and Mehlich-1 extractable plant nutrients and rating from 0 to 6 in. soil samples taken November 2004 on the Cullars Rotation. Particularly relevant values are shaded.

	Treatments[1]					Soil	Soil-test rating and Mehlich-1 extractable nutrients[2]			
Plot	Description	N	P	K	S	pH	P	K	Mg	Ca
							mg/kg			
A	No N/+legume	0	✔	✔	✔	6.1	VH 63	M 46	H 28	423
B	No N/no legume	0	✔	✔	✔	6.0	VH 57	M 44	H 23	330
C	No soil amendments	**0**	**0**	**0**	**0**	5.2	L 5	L 21	L 6	73
1	No winter legumes/ + N	✔	✔	✔	✔	6.2	H 46	M 52	H 33	371
2	No P	✔	0	✔	✔	6.2	VL 3	M 34	H 31	285
3	Standard fertilization, no micronutrients	✔	✔	✔	✔	6.1	VH 51	M 42	H 37	395
4	4/3 K	✔	✔	✔	✔	6.2	VH 81	M 47	H 38	525
5	Rock phosphate	✔	✔	✔	✔	6.0	EH 200	M 47	H 30	732
6	No K	✔	✔	0	✔	6.3	EH 101	VL 13	H 43	541
7	2/3 K	✔	✔	✔	✔	6.2	VH56	M 37	H 34	826
8	No lime	✔	✔	✔	✔	4.7	VH 68	L 26	L 3	200
9	No S	✔	✔	✔	0	6.2	VH 90	M 50	H 46	1,100
10	Standard fertilization + micronutrients (Zn,Cu, Mn, Fe, & B)	✔	✔	✔	✔	6.3	VH 85	M 66	H 36	953
11	1/3 K	✔	✔	✔	✔	6.1	VH 67	L 28	H 32	680

[1]Standard lime and fertilizer treatments: limed to pH 5.8 to 6.5; 100 lb P_2O_5/A per 3-yr rotation; 270 lb K_2O/A per 3-yr rotation; 90 lb N/A on cotton; 120 lb N/A on corn; 60 lb N/A topdress on small grain; 40 lb sulfate-S/A applied as gypsum to cotton and small grain.

[2]Rating based upon cotton on sandy soils (C.E.C. < 4.6 meq/100 grams); VL=very low; L=low; M=medium, H=high (desirable range); VH=very high; EH=extremely high (Adams et al., 1994).

drops below 5.8. Although B fertilization of cotton and reseeding clover, and Zn fertilization of corn are routinely recommended by Auburn University's Soil Testing Laboratory (Adams et al., 1994), no crop demonstrated a significant response to micronutrient fertilization in the period 1995-2004. Mean yields of cotton, corn, soybean, and small grain from 1995 through 2004 seem to reflect the long-term trends (**Table 2, Figure 1**).

Long-term trends, as illustrated by the 5-year running average yields in **Figure 1**, show periods of yield increases and dramatic decreases. Because this is a non-irrigated experiment, short-term droughts and other weather-related disasters during the growing season can have dramatic effects on yields. Year-to-year yield variability is high. The downward yield trends in the late 1970s and early 1980s reflect management problems when technical assistance was not available to address the day-to-day management of these plots. Nevertheless, the relative yields of the different fertility treatments remained about the same.

In the last 10 years of the study (1995-2004), the yield losses when P was not applied (compared to standard fertilization...lime, N,P,K,S...with micronutrients) were 57, 66, 69, 61, and 73% for cotton, corn, soybean, wheat, and clover, respectively.

When K was not applied, the yield losses were 95, 59, 40, 33, and 37% for cotton, corn, soybean, wheat, and clover, respectively.

Table 2. Mean crop yields on the Cullars Rotation, 1995-2004.

Plot	Treatment	Cotton lint, lb/A	Corn grain, bu/A	Soybean grain, bu/A	Wheat grain, bu/A	Clover dry matter, lb/A
A	No N/+legume	840 (88)	76 (78)	32 (91)	22 (41)	2870 (86)
B	No N/no legume	790 (83)	53 (54)	31 (89)	17 (31)	—
C	No soil amendments	20 (2)	1 (1)	1 (3)	0 (0)	0 (0)
1	No winter legumes/ + N	970 (102)	95 (97)	32 (91)	51 (94)	—
2	No P	410 (43)	33 (34)	11 (31)	21 (39)	910 (27)
3	Standard fertilization, no micronutrients	970 (102)	93 (95)	33 (94)	50 (93)	2940 (88)
4	4/3 K	850 (89)	88 (90)	32 (91)	50 (93)	2840 (85)
5	Rock phosphate	840 (88)	94 (96)	33 (94)	55 (102)	3080 (92)
6	No K	50 (5)	40 (41)	21 (60)	36 (67)	2090 (63)
7	2/3 K	920 (97)	101 (103)	32 (91)	54 (100)	3270 (98)
8	No lime, pH=4.9	200 (21)	39 (40)	2 (6)	14 (26)	560 (17)
9	No S	870 (92)	90 (92)	32 (91)	55 (102)	2480 (74)
10	Standard fertilization + micronutrients	950 (100)	98 (100)	35 (100)	54 (100)	3330 (100)
11	1/3 K	720 (76)	95 (97)	33 (94)	52 (96)	2700 (81)

Values in parentheses represent percentage of yield compared to "standard fertilization + micronutrients." Standard lime and fertilizer treatments: limed to pH 5.8 to 6.5; 100 lb P_2O_5 /A per 3-yr rotation;270 lb K_2O /A per 3-yr rotation; 90 lb N/A on cotton; 120 lb N/A on corn; 60 lb N/A topdress on small grain.

These results clearly illustrate the importance of adequate P and K fertilization. The data also indicate that adequate fertilization raises crop yields and sustains crop yields. The yield data in **Table 2** and **Figure 1** show that with adequate liming and fertilization, and proper management, cotton production is sustainable. **These results dispel the fallacy that cotton production harms soil productivity.**

Coincidentally, record crop yields have been recorded on the Cullars Rotation since 1996 when we switched to genetically modified varieties, and in 1997 when we switched to conservation tillage:

- 1996: 1,580 lb/A of cotton lint/A (3+ bales) on plot 7
- 1996: 75.1 bu/A of soybeans on plot 10
- 1999: 161 bu/A of corn on plot A
- 1999: 63.5 bu/A of wheat on plot 9
- 2000: 64.7 bu/A of wheat on plot 5
- 2001: 70.0 bu/A of wheat on plot 11
- 2004: 1,930 lb/A of cotton lint (almost 4 bales) on plot 1

These record yields are attributed to: 1) favorable growing seasons, 2) adoption of deep tillage to disrupt traffic pans, 3) conservation tillage which allows better moisture infiltration, higher water holding capacity, and cooler soils, 4) higher plant populations, 5) timely planting, 6) better weed control, especially through the new genetically modified varieties, and 7) less insect problems as a result of the boll weevil eradication program and the new Bollgard® cotton varieties.

Potassium movement and accumulation in soil profile (Figure 2). Soil samples taken in incremental depths to 48 in. from the K-variable treatments reveal that large quantities of K accumulate in the upper soil profile in this loamy sand with a cation exchange capacity (CEC) near 3.0 meq/100 grams. Potassium depletion occurs, especially in the top 24 in. of the soil profile, with inadequate K fertilization. Leaching occurs below the surface with the higher K rates as indicated by the Mehlich-1 extractable K levels. Routine, plow-layer soil sampling reflects soil test K increases associated with higher K fertilization rates. Note that the application of sulfate-S (as gypsum) appeared to increase K leaching.

Summary

The Cullars Rotation experiment continues to document long-term trends in non-irrigated crop yields and soil changes due to variable rates of P, K, S, micronutrients, and lime. It provides a valuable and accessible teaching tool for monitoring crop nutrient deficiencies. It also is a source of uniform soil with variable fertility conditions for allied studies. No other such resource exists in the Coastal Plain of the southern U.S. BC

Dr. Mitchell (E-mail: mitchc1@auburn.edu) is Professor and Extension Specialist-Nutrient Management and Soil Science, and Dr. Delaney is Extension Specialist-Row Crops in the Agronomy and Soils Department, both with Auburn University. Dr. Balkcom is Affiliate Assistant Professor at Auburn University and Research Agronomist, National Soil Dynamics Laboratory, USDA-ARS, Auburn.

Acknowledgment

The Cullars Rotation is one of several long-term soil fertility experiments maintained by the Auburn University Department of Agronomy and Soils and the Alabama Agricultural Experiment Station in cooperation with the USDA-ARS National Soil Dynamics Laboratory. This experiment has received periodic support through the commodity checkoff programs of the Alabama Wheat and Grain Crops Committee, the Alabama Soybean Committee and the Alabama Cotton Commission.

For more about the Cullars Rotation visit this website: >www.ag.auburn.edu/agronomy/cullars.htm<.

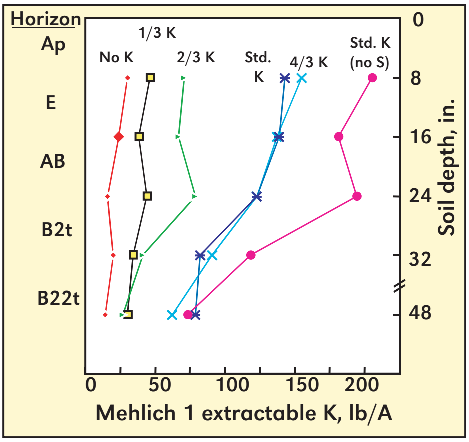


Figure 2. Soil profile K after 90 years of K fertilization, averaged across crop treatments. (Data points for each sampled depth increment are at the bottom of each in the graph. Depth increments are 8 in. except for the 16 in. increment from 32 to 48 in.)

Literature Cited

Adams, J.F., C.C. Mitchell, and H.H. Bryant. 1994. Soil test fertilizer recommendations for Alabama Crops. Ala. Agric. Exp. Stn. Dep. Ser. No. 178. Auburn University, AL.

Atkinson, G.F. 1891. Black rust of cotton. Agric. Exp. Stn. Bul. No. 27. Agricultural and Mechanical College of Alabama, Auburn, AL.

Atkinson, G.F. 1892. Some leaf blights of cotton. Agric. Exp. Stn. Bul. No.36. Agricultural and Mechanical College of Alabama, Auburn, AL.

Williamson, J.T. and M.J. Funchess. 1923. Fertilizer experiments with cotton. Agric. Exp. Stn. Bul. 219. Alabama Polytechnic Institute. Auburn, AL.

TOOLBOX

PKalc Software Checks Nutrient Balance

"Toolbox" is a feature on the PPI/PPIC website which holds free downloadable software tools for improved nutrient management. One useful tool is called PKalc (v.1.13), a simple balance calculator which helps users determine if phosphorus (P) and potassium (K) nutrient additions are keeping up with removal by crops.

PKalc and other programs can be accessed for free at:

>www.ppi-ppic.org/toolbox> BC

Barley Production in Semiarid Regions—Making the Malting Grade

By Ross McKenzie and Grant Jackson

Field trial results indicate that malt barley yield was most influenced by seeding date and matching plant-available water with a crop nitrogen (N) requirement of 1.2 lb N/bu.

Malt barley production has moved west into semiarid regions of the northern Great Plains with the on-set of fusarium blight in the eastern regions. Weather conditions, mainly drought, are often unfavorable for malting barley quality in semiarid regions.

Well-fertilized barley fields subject to moisture stress will result in grain samples that are higher in protein (<12.5 to 13.0% accepted for malt) and have reduced kernel plumpness (>70 to 80% plump required for malt). Nitrogen fertilizer additions have been shown to increase barley yield and protein content, and to depress kernel plumpness. Increasing plant-available water increases yield and plumpness, while decreasing protein.

In dryland agriculture, finding the appropriate balance between nutrient supply and moisture is critical to successful production of high quality malt barley.

Research trials were conducted in northern Montana and southern Alberta to evaluate how fertilizer additions can influence the yield and quality of malt barley. Fourteen experiments from the Triangle region of north central Montana were considered, using N fertilizer rates of 0 to 120 lb N/A. Adequate phosphorus (P) and potassium (K) were added. The database was divided into two groups: seven trials with yields of <70 bu/A, and seven trials of >70 bu/A. A second database consisted of 15 experiments from Alberta's Brown, Dark Brown, Thin Black, Black,

Early seeding and appropriate N application rates related to moisture availability are keys for malt barley production in the northern Great Plains.

and Gray Wooded soil zones. All plot areas received an application of 27 lb P_2O_5/A and N treatments that varied between 0 and 140 lb N/A. The Alberta data were organized into two databases, seven locations with yields of <100 bu/A and eight locations with yields that were >100 bu/A. Regression equations were developed using initial nitrate (NO_3)-N in 3 ft. (Montana) or 2 ft. (Alberta) of soil plus fertilizer N as the independent variable vs. dependent variables of grain yield, grain protein content, and kernel plumpness. A second Alberta study on irrigated and dryland sites in the Brown, Dark Brown, and Black soil zones considered 14 sites using the treatments: 1) 0, 36, 72, 108, and 144 lb N/A, 2) 0, 13, 26, and 39 lb P_2O_5/A, 3) 0, 27, and 53 lb K_2O/A, 4) 0, 9, and 18 lb sulfur (S)/A, and 5) three seeding dates at 10-day intervals and seeding rates of 150, 200, 250, 300, and 350 viable seeds/m^2.

The results from the Montana and first

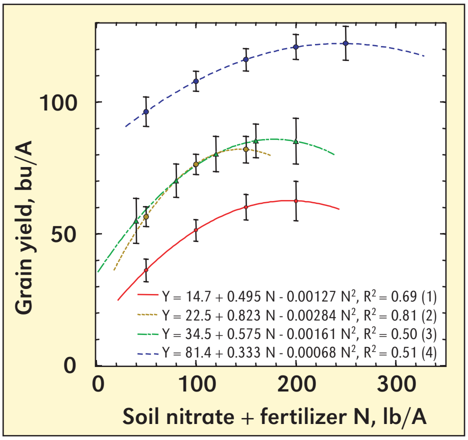


Figure 1. Effect of N on barley grain yield.

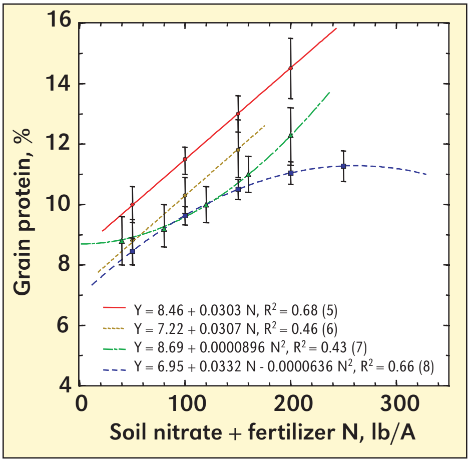


Figure 2. Effect of N on barley grain protein.

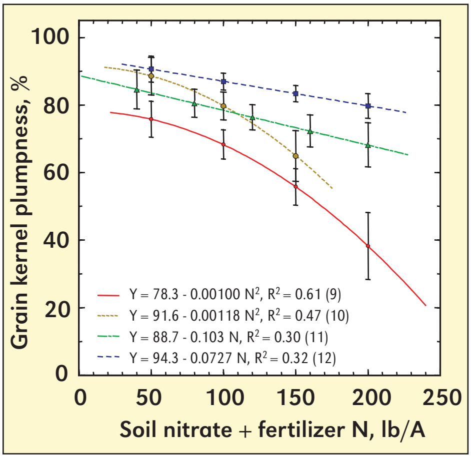


Figure 3. Effect of N on barley kernel plumpness.

Alberta study clearly show how malt barley responds to fertilizer and soil N levels. Increasing N supply resulted in increasing grain yield (**Figure 1**) and grain protein (**Figure 2**) for all yield groups considered, and a decrease in kernel plumpness (**Figure 3**). Equations 1, 5, and 9 are for the <70 bu/A Montana data, equations 2, 6, and 10 are for the >70 bu/A Montana data, equations 3, 7, and 11 are for the Alberta <100 bu/A data, and equations 4, 8, and 12 are for the Alberta >100 bu/A data. With the low yielding, high water stress group from Montana, water stress conditions resulted in a modest yield response (**Figure 1**–Equation 1), while grain protein increased (**Figure 2**–Equation 5) and kernel plumpness declined (**Figure 3**–Equation 9) dramatically. Grain yield increase to N additions were large in the high yielding southern Alberta trials with minimal water stress (**Figure 1**–Equation 4), while modest increases were observed in grain protein (**Figure 2**–Equation 8), and minimal declines were noted in kernel plumpness (**Figure 3**–Equation 12).

While optimum grain yields were found to occur commonly in the 130 to 150 lb N/A range (**Figure 1**), this was not the case when the critical factor of malt barley quality, grain protein (**Figure 2**), and kernel plumpness (**Figure 3**), were considered. While most of the barley grain samples were less than the 13.0 to 13.5% level in this study, under dry conditions the addition of N resulted in a steep linear increase in grain protein (**Figure 2**–Equation 5), while only a modest curvilinear increase was noted under the low water stress conditions (**Figure 2**–Equation 8). Similarly, increasing N rate resulted in a decline in kernel plumpness of almost 50% with the high water stress trials (**Figure 3**–Equation 9), while the reduction was less than 10% for the low water stress, high yielding environment (**Figure 3**–Equation 12). These results indicate that the ability to grow a premium quality malt barley sample is severely limited under water stress conditions, a fact of life for semiarid dryland farmers.

The second Alberta study evaluated malt barley response to N using the available soil N supply as determined from the N uptake by the unfertilized check plot. This is significant in that the pre-plant soil test nitrate-N level was generally 18 to 36 lb N/A less than the unfertilized crop N uptake, with deviations of more than 45 lb N/A not uncommon. When the N uptake and fertilizer N additions were combined, they found that maximum malt barley grain yields were achieved at levels of approximately 1.2 lb N/bu (data not shown). This N level is very similar to application recommendations used in Montana, and considerably less than recommendations for hard red spring wheat (2.5-3.0 lb N/bu). Drier conditions in the second Alberta study meant that 43% of the trials had more than 13% grain protein when grain yield was optimized. They suggested that for this data set the optimum N rate for malt grain protein was more difficult to predict, and ranged from 0.7 to 1.2 lb N/bu, depending on environmental conditions.

The second Alberta study also focused on the impact of P, K, and S nutrition, as well as seeding rate and date for malt barley. Unfortunately, when all sites were combined the application of P, K, and S fertilizers did not affect malt barley grain yield or quality (data not shown). An economic analysis of grain yield response to P application showed a positive response at four of the 12 sites when the lowest P rate was used. Hot summer weather following a cool spring may explain the lack of a P response in most of this study. On an individual site basis, 3 locations showed a very modest, but significant grain yield response to K additions, ranging from 2.3 to 5.8%. Most of the soils in this second Alberta study had soil test K levels of greater than 100 parts per million (ppm), a level which has been shown to be sufficient for barley production in this region.

Seeding delays of approximately 20 days reduced barley grain yields by an average of 20% in the second Alberta study,

Nitrogen fertilizer response on stubble is dramatic in these barley plots in the Dark Brown soil zone near Carmangay, Alberta.

while it had little effect on grain protein or kernel plumpness (data not shown). With increasing drought stress on the barley crop, the yield loss with delayed seeding was even greater. Increasing seeding rates from 150 to 350 viable seeds/m^2 resulted in small yield gains and slight reductions in grain protein and kernel plumpness.

The most beneficial agronomic practices for malt barley production in the semiarid northern Great Plains were early seeding and application of N fertilizer at rates appropriate to the expected availability of moisture and soil N. Unfortunately, in the absence of an irrigation water supply this makes the selection of fertilizer N rates a major challenge for dryland farmers, and increases the risk of achieving a malting grade for barley grown. BC

Dr. McKenzie (ross.mckenzie@gov.ab.ca) is with the Crop Diversification Division of Alberta Agriculture, Food and Rural Development in Lethbridge, Alberta T1J 4V6 Canada. Dr. Jackson is located at the Western Triangle Agricultural Research Center, Montana State University, Conrad.

References

Jackson, Grant. 2000. Nitrogen fertilization of dryland malt barley for yield and quality. Mont. State Univ. Ext. Ser. Fert. Facts no. 24.; http://landresources.montana.edu/FertilizerFacts/24_Nitrogen_Fertiliztion_of_Dryland_malt_Barley.htm

McKenzie, R.H., A.B. Middleton, and E. Bremer, 2005. Fertilization, seeding date, and seeding rate for malting barley yield and quality in southern Alberta. Can. J. Plant Sci. 85: 603–614.

High Soybean Yield Can Mean Higher Concentrations of Isoflavones

By Xinhua Yin and Tony J. Vyn

Across a range of studies involving tillage, row width, and potassium (K), the higher soybean yield levels were associated with markedly higher isoflavone concentrations...but with little change in oil and protein. Part of the increase of isoflavones with seed yield may have resulted from a parallel increase of seed K concentrations.

Soybeans are traditionally produced for the oil and protein in the seed, which are the economically important quality components of the crop. Seed of current U.S. soybean cultivars contains on average approximately 41% protein and 21% oil on a dry weight basis (Hartwig and Kilen, 1991). Another component that may someday gain economic value is the content of isoflavones, because of their positive potential role in prevention of cancer, heart disease, osteoporosis, and menopausal symptoms (Caragay, 1992; Hasler, 1998).

Our objective was to determine the relationships of the concentrations of isoflavones, oil, and protein with seed yield of soybean across a wide variety of production environments.

We conducted investigations at five sites in Ontario from 1998 through 2000. Each site had a history of at least 5 years of continuous no-till. Soil test K levels in the 0 to 6 in. depth ranged from low…35 parts per million (ppm)…to very high (155 ppm). Treatments included both rates and placement (broadcast vs. banded) of K fertilizer at all sites, and fall disk tillage to a depth of 4 in. as a variable at two of the sites. All remaining treatments were grown with no tillage. The investigations involved a total of four varieties. For further details, see Yin and Vyn (2005).

We grouped the results into four yield categories: low (<37 bu/A), medium (37 to 45 bu/A), high (45 to 52 bu/A), and very high (>52 bu/A). We found that oil concentration differences among the four yield categories were quite small (**Table 1**). For example, oil concentration decreased from 21.7% to 20.8% when yield group increased from low to very high. Protein concentration in seed did not differ significantly among the four yield categories. Isoflavone concentrations, however, increased by almost 50% as yield group increased from low to high.

Yield-promoting factors, while slightly reducing oil, can boost levels of isoflavones in soybean seeds.

Table 1. Oil, protein, and total isoflavone concentration of soybeans, grouped according to yield.

Yield group, bu/A	Oil	Protein	Isoflavones, ppm
	- - - - - - - %	- - - - - - -	
15 to 37	21.7	40.7	1,360
37 to 45	21.5	40.3	1,590
45 to 52	21.0	40.3	2,020
52 to 70	20.8	40.5	2,010

All three types of isoflavones—daidzein, genistein, and glycitein—increased significantly as seed yield increased from the low to the high category (**Table 2**). Daidzein had a greater increase in concentration as soybean yields climbed than either genistein or glycitein. Genistein increased more with yield than glycitein. This suggests that daidzein is the most variable and glycitein is most stable of the isoflavone components. Overall, on a concentration basis, isoflavones varied with soybean yield level to a much greater magnitude than oil and protein.

Soybean seed composition can be affected by cultivars, management practices, and environmental factors. In previous research (Vyn et al., 2002), we observed that K fertilizer application significantly increased soybean seed yield and isoflavone concentrations simultaneously on low-testing K soils; this observation indirectly supports the finding in the current study that individual and total isoflavone concentrations increased as seed yield went up. Our results suggest that high soybean seed yield can be accompanied by high concentrations of isoflavones without any large declines in oil and protein concentrations.

Although linear regression analysis showed that seed oil concentration was negatively and linearly related to seed yield, the decrease was quite small, about 0.3% for a 10 bu/A increase in yield. The relationship between protein concentration and seed yield was not significant. However, concentrations of isoflavones were all positively and linearly related with seed yield. The concentration increases—per 10-bu/A yield increase—amounted to 287 ppm for total isoflavones, 168 ppm for daidzein, 110 ppm for genistein, and 8 ppm for glycitein.

Table 2. Concentrations of the three isoflavone components all increased with yield.

Yield group, bu/A	Daidzein	Genistein	Glycitein
	- - - - - - - - - - - -	ppm - - - - - - - - - - - -	
15 to 37	580	660	110
37 to 45	680	780	110
45 to 52	960	930	130
52 to 70	970	920	130

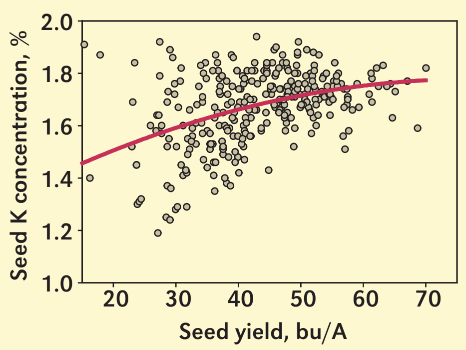


Figure 1. Seed K concentration generally increased with seed yield.

Both K and isoflavone concentrations increased with yield (**Figure 1, Table 1**). Did the increased K cause the increased levels of isoflavones? The answer from our detailed analyses is that K appears only partially responsible.

Multiple-factor linear regression analysis—which included K application and placement, cultivar, location, and growing season as the independent factors—showed that the seed yield differences were not only attributed to the K application and placement effects, but were also attributable to cultivars, locations, and growing seasons. Therefore, the significant relationships of seed quality components with seed yield observed in this study were influenced by more than K application and placement. Several other factors contributing to yield were also associated with increased isoflavones.

In summary, the strong positive relationship of total isoflavone concentration with seed yield and the weak association

Soy foods are becoming more popular for health reasons.

of oil and protein concentrations with seed yield suggests that there was no big trade-off of seed yield or oil and protein concentrations for isoflavone concentration in soybean. Rather, isoflavone concentration significantly increased as seed yield went up, without substantial decreases in oil and protein concentrations. Some of the increase of isoflavones with seed yield may have resulted from a concomitant increase of seed K concentrations with yield.

This positive relationship between total isoflavone concentration and seed yield is very encouraging, as it suggests that high soybean yield could be compatible with high quality from an isoflavone-based functional food perspective. Furthermore, high total isoflavone concentration in seed can be achieved without large decreases in oil and protein concentrations. BC

Dr. Yin is Assistant Professor at Mid-Columbia Agricultural Research and Extension Center, Oregon State University, Hood River, Oregon; e-mail: XinhuaYin@oregonstate.edu. Dr. Vyn is Professor of Agronomy, Purdue University, West Lafayette, Indiana; e-mail: tvyn@purdue.edu.

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References

Caragay, A.B. 1992. Cancer-preventive foods and ingredients. Food Technol. 4:65-68.

Hartwig, E.E. and T.C. Kilen. 1991. Yield and composition of soybean seed from parents with different protein, similar yield. Crop Sci. 31:290-292.

Hasler, C.M. 1998. Scientific status summary on functional foods: Their role in disease prevention and health promotion. Food Technol. 52:63-70.

Vyn, T.J., X.H. Yin, T.W. Bruulsema, C.J.C. Jackson, I. Rajcan, and S.M. Brouder. 2002. Potassium fertilization effects on isoflavone concentrations in soybean [Glycine max (L.) Merr.]. J. Agric. Food Chem. 50:3501-3506.

Yin, X.H. and T.J. Vyn. 2005. Relationships of isoflavone, oil, and protein in seed with yield of soybean. Agron. J. 97:1314-1321.

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Balancing Short-Term and Long-Term Goals in Nutrient Management

By A. Dobermann, K.G. Cassman, D.T. Walters, and C. Witt

Four case studies are presented on cumulative crop response to repeated fertilizer additions. Greatest benefits in terms of yield, nutrient use efficiency, and soil fertility accrued over time in those systems that were managed with repeated, balanced nutrient additions that also led to improvements in soil fertility. Fertilizer recommendations must consider short-term as well as long-term crop response to applied fertilizer. Changes in soil nutrient pools need to be accounted for in evaluating nutrient management strategies by estimating the system level nutrient use efficiency.

Fertilizer recommendations are often derived from agronomic trials that focus on optimizing nutrient inputs with regard to achieving high net return in the crop to which the nutrient was applied. When a field experiment results in a small yield increase due to nutrient addition that is not statistically significant, the conclusion is often made that there is no need to apply that nutrient. This concept may lead to imbalanced fertilizer use and negative nutrient balances that threaten soil fertility and crop productivity over the longer term.

Case study 1: Cotton response to potassium (K)

Cassman et al. (1989) studied the response of irrigated cotton to K applications on a vermiculitic soil (**Figure 1**). Cotton yield was closely related to plant and soil K status and declined without K addition due to depletion of soil K, but a yield increase occurred in each successive year at the highest K rate. Annual rates of 129 or 257 lb K_2O/A resulted in increased cumulative seed yield by 13 to 21%, but 514 lb K_2O/A produced an increase of 42%. Soil K and soil organic matter contents declined in the control treatment, which shifted the K equilibrium towards fixation at interlayer clay sites. With high levels of K input, partial saturation of K fixation sites was achieved, resulting in increasing plant availability of added K and a 50% increase in the crop recovery efficiency of fertilizer-K. Those benefits were not achieved with small K applications or they would have been masked if the study had been conducted for a short time only.

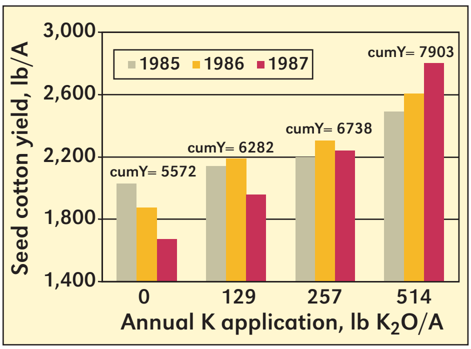

Figure 1. Response of annual and cumulative (cumY) seed cotton yield to annual K applications on a Vertisol.

Case study 2: Soybean response to phosphorus (P)

Key management decisions on acid, tropical soils include whether to invest in fertilizer P and how to apply it over time. On an Ultisol in Hawaii, P recovery by soybeans and agronomic efficiencies of applied P increased over time in two cropping seasons with different yield potential and at all levels of P input (Cassman et al., 1993). Cumulative P uptake and seed yield of all four crops grown were closely related to the level of P input (**Table 1**). The net P budget was positive in all +P treatments and resulted in an increase in extractable soil P, a reduction in the proportion of P fixed from subsequent P additions, greater P use efficiency, and an increase in nitrogen (N) uptake by soybeans. Cumulative yield response increased over time, which also means that the marginal return from investment in P fertilizer will increase with time.

Table 1. Cumulative soybean yield (cumY, bu/A) and P uptake (cumP, lb P/A), crop recovery efficiency (RE_P), and agronomic efficiency (AE_P) of annual P applications on an acid Ultisol. F=fall soybean; S=summer soybean.

Annual P input		1988 F	1989 F	1989 S	1990 S
lb P_2O_5/A	cumP	RE_P (ΔP uptake/P applied, lb/lb)			
0	27	–	–	–	–
72-102	50	0.08	0.14	0.2	0.29
143-205	67	0.08	0.13	0.19	0.22
429-614	78	0.04	0.05	0.08	0.09
lb P_2O_5/A	cumY	AE_P (ΔSeed yield/P applied, lb/lb)			
0	103	–	–	–	–
72-102	155	12.7	18.2	22.5	44.1
143-205	177	10.9	15.0	14.7	25.6
429-614	183	4.1	5.5	6.1	8.9

Note: The delta symbol (Δ) indicates "change in"

Case study 3: Rice response to P and K

Many P and K recommendations in irrigated rice systems of Asia are based on field trials that emphasize single-season yield response to nutrient applications. When no significant yield increase is measured, the recommendation is often not to apply that nutrient, which can lead to depletion of soil P and K (Dobermann et al., 1998). Although the initial yield response of lowland rice to P or K applications is often small, large cumulative yield increases accrue over time (Witt et al., 2004).

In the example shown in **Figure 2** (Witt et al., 2004), initial yield increases due to P or K application were not significant (<0.22 tons/A). However, yield increases were consistent and became larger over time because plant available soil P and K pools became exhausted. Over 9 years (18 crops), neglecting P or K application caused a grain production loss of 7.4 or 4.9 tons/A, respectively. Similar patterns were observed at other sites in Asia. Fertilizer requirements would be underestimated if they were based on the short-term yield response without considering nutrient removal with grain and straw. Therefore, in a new site-specific nutrient management concept, P and K maintenance rates are calculated based on a nutrient input-output model (Dobermann et al., 2004).

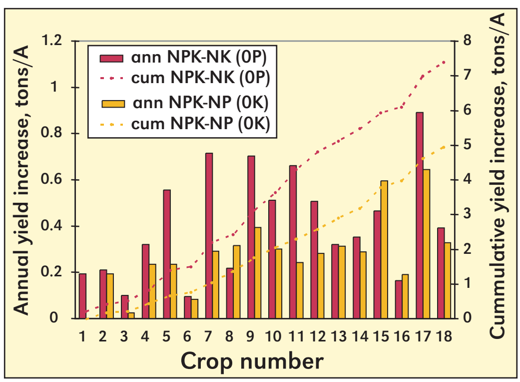

Figure 2. Annual and cumulative yield increases of irrigated rice due to P or K applied to each crop on a Vertisol at Maligaya, Philippines, 1968-76.

Case study 4: Nitrogen in irrigated corn systems

Maintenance of soil organic matter (SOM) is an important goal in agriculture, both in terms of soil fertility and increasing the sequestration of atmospheric carbon dioxide (CO_2) in soil. Because of the tight C:N ratio in SOM, sequestration of C requires sufficient N. This role of N should also be considered in assessing fertilizer N use efficiency and designing long-term N management strategies.

In the example shown in **Table 2**, the recommended continuous corn system represented management for yields of approximately 80% of yield potential. In the intensive system, management was intensified to achieve 90 to 95% of yield potential and an extra amount of N was applied in fall to support crop residue decomposition and humification. In a 4-year period the cumulative crop residue C input was 22% larger in the intensive system than with recommended management, but there was no difference in C respiration from the soil. Intensive management resulted in significant C *and* N sequestration in SOM, whereas a net loss of soil C and N occurred in the recommended system. Based on the annual partial factor productivity (PFP) of applied N, the recommended system appeared to be more N-efficient because it produced 1.29 bu grain/lb N applied (0.86 lb grain N/lb N) as opposed to 0.93 bu grain/lb N (0.65 lb grain N/lb N) in the intensive system. However, when the net change in soil N was included, the intensive system had a higher *system level* N use efficiency (0.83) than the recommended system (0.56, **Table 2**) because extra N fertilizer contributed to build-up of SOM. Over time, this will increase the indigenous soil N supply and lead to an increase in annual PFP, which cannot be achieved in the more conservatively managed recommended system.

Dr. Dobermann discusses high yield corn research at the recent Ecological Intensification Field Day.

Table 2. Nitrogen use efficiency in irrigated corn systems with recommended (Rec) or intensive (Int) management on a Mollisol at Lincoln, Nebraska, 2000-2004.

	Rec[1]	Int[2]
Average corn (maize) yield, bu/A	223	252
Average fertilizer-N rate, lb/A	174	272
4-year C & N budget (May 2000 to May 2004)		
Crop residue input, tons C/A, aboveground	9.6	11.8
Soil+root respiration, tons CO_2-C/A	12	11.6
Measured change in soil C, tons/A	-0.5	2
Fertilizer-N input, lb/A	697	1090
N removal with grain, lb/A	598	705
Measured change in soil N, lb/A	-205	196
Nitrogen use efficiency		
bu grain/lb N applied, PFP	1.29	0.93
lb grain N/lb N applied	0.86	0.65
lb grain N+change in soil N/lb N applied	0.56	0.83

[1] 18,500 plants/A; soil-test based fertilizer rates, 2 N splits
[2] 26,000 plants/A; increased fertilizer rates, 4 N splits+45 lb N A applied in fall on crop residue before plowing

Conclusions

Fertilizer management strategies should be balanced with regard to achieving high short-term efficiency as well as maximizing the cumulative crop yield response over time. Although the cost of fertilization is usually charged to a single crop, long-term benefits accruing from residual fertilizer availability (P, K) or increases in soil C and N storage should be included in evaluating fertilizer economics. Contributions of added nutrients to both crop uptake and soil nutrient supply must be accounted for in assessing the *system level efficiency* of applied nutrients. BC

Dr. Dobermann, Dr. Cassman, and Dr. Walters are with the Department of Agronomy and Horticulture, University of Nebraska, Lincoln; e-mail: adobermann2@unl.edu. Dr. Witt is

Information Agriculture Conference Continues with Successful 2005 Event

Participants, speakers, and exhibitors at the recent Information Agriculture Conference (InfoAg 2005) in Springfield, Illinois, agreed that a tremendous amount of progress has taken place in precision agriculture and information management over the past 10 years. And with no sign of the trend reversing, dates have been tentatively set for another edition of the conference in 2 years…July 9 to 13, 2007…in Springfield.

Hot topics at InfoAg 2005 included auto-guidance for equipment, scouting and sensing techniques for soybean rust and other crop and soil conditions, wireless technologies, variable-rate application, and leveraging precision investment. The event is organized by the Foundation for Agronomic Research (FAR) in cooperation with PPI/PPIC.

"Much of the appeal of the Conference is the networking and informal communication that takes place among those at the sessions and in the exhibit areas," says Dr. Harold F. Reetz, Jr., President of FAR, located at Monticello, Illinois. "It's amazing that 10 years ago at the first InfoAg Conference, many of the technologies and tools now available were still in development stages. Yield monitors and the Internet were just coming on the scene; auto-guidance and detailed GIS records were new concepts. Today all these are part of integrated management systems of farmers, dealers, and consultants. Several of the people on the program in 2005 have been modern-day 'pioneers' who were willing to try new ideas. Of course, the bottom line goal is still a more efficient, profitable, and environmentally-friendly agriculture." Attendance this year reached more than 550, with participants from all over the U.S., Canada, and several other countries.

InfoAg 2005 offered a multi-track program with more than 100 presentations and demonstrations to accommodate every level of technology know-how.

The exhibit hall for InfoAg was coordinated by CropLife Media Group of Willoughby, Ohio, publishers of *CropLife* magazine and the *PrecisionAg Buyer's Guide*.

"We want to thank everyone who attended, supported, and contributed to the success of InfoAg 2005," Dr. Reetz added. "More details about InfoAg 2007 will be available later."

That information and presentations from the 2005 conference will be posted for access at the Information Agriculture website: >**www.infoag.org**<. BC

Director, PPI/PPIC-IPI Southeast Asia Program, Singapore.

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References

Cassman, K.G., B.A. Roberts, T.A. Kerby, D.C. Bryant, and S.L. Higashi. 1989. Soil Sci. Soc. Am. J. 53, 805-812.

Cassman, K.G., P.W. Singleton, and B.A. Linquist. 1993. Field Crops Res. 34, 23-36.

Dobermann, A., K.G. Cassman, C.P. Mamaril, and J.E. Sheehy. 1998. Field Crops Res. 56, 113-138.

Dobermann, A., C. Witt, and D. Dawe (ed). 2004. Increasing productivity of intensive rice systems through site-specific nutrient management. Science Publishers, IRRI, Enfield & Los Baños.

Witt, C., A. Dobermann, R.J. Buresh, S. Abdulrachman, H.C. Gines, R. Nagarajan, S. Ramanathan, P.S. Tan, and G.H. Wang. 2004. Better Crops 88 (4), 32-35.

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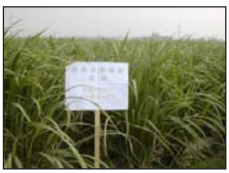
International Section

SOUTHEAST CHINA

Diversifying Lowland Production with Water Bamboo

By Fang Chen, Lina Jiang, and Jianrong Fu

The incorporation of water bamboo into lowland production systems is becoming an increasingly popular practice. Farmers recognize advantages over strict rice production. However, research indicates much more may be gained by implementing proper nutrient management.



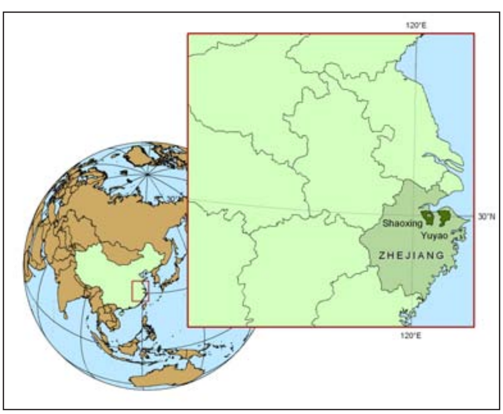
A network of research and public demonstration plots is showing advantages of proper fertilization for water bamboo.

In Zhejiang Province and adjoining areas, water bamboo can be part of a lowland rice production system.

Water bamboo (*Zizania caduciflora*) continues as a popular vegetable in south China. The crop is a water-loving rhizocarpic grass. Its edible part is the succulent stem created by fungal (*Ustilago esculenta*) infection and subsequent release of the plant growth hormone indole acetic acid (IAA).

The growing habitat of water bamboo is rather similar to rice, so a water bamboo-rice crop rotation is a natural fit. The selected water bamboo cultivar should be adapted to local rice soil conditions (high soil water table) and cause no negative effects in rice. Where implemented, the prevailing practice is a double-crop system wherein water bamboo is first transplanted in March to April and harvested in autumn. During winter, above-ground plant parts die off and new sprouts are generated the following spring, and the second harvest occurs in summer. The rotation is completed by transplanting late rice immediately after this second water bamboo harvest.

Recently, a rapid increase in planted area has been observed in Zhejiang, Jiangsu, and Shanghai Provinces. The shift is primarily a result of the system's highly efficient use of lowland soil environments. Thus, planting index can be increased from a one-crop system (late rice-fallow) to a three-crop system (autumn water bamboo-late rice-summer water bamboo). Damage from insects and plant disease is reduced with the three-crop system and income per unit area is greatly enhanced (more than US$11,100 higher than a single rice cropping system).



Water bamboo requires a good nutrient supply in order for its roots to flourish and support its large above-ground biomass, which extends 1 to 2 meters. At present, local farmers usually use high rates of nitrogen (N) and phosphorus (P) fertilizers for water bamboo,

Water bamboo stems from balanced fertilization plots are shown at left, compared to stems from plots with common fertilizer practice at right.

Table 1. Autumn water bamboo response to balanced fertilization, Zhejiang.

$N-P_2O_5-K_2O$, kg/ha	Yield, kg/ha	Yield, %
375-180-225 (OPT)	21,912 A[1]	–
375-180-338 (+K)	21,201 A	-3.35
375-0-225 (-P)	19,137 B	-14.50
375-180-0 (-K)	19,232 B	-13.93

[1]Yield values followed by the same letter are not significantly different.

but largely ignore potassium (K) and micronutrient fertilization. The Soil and Fertilizer Institute of Zhejiang Province initiated a network of research and public demonstration fertilization trials in 2002 on water bamboo in Yuyao County and Shaoxing County in the province. A summary of the results to date indicates the following.

1) Improved treatments promoted overall plant growth, while increasing plant height, leaf length, leaf width, and numbers of tillers. Yield was highest with application of 375-180-225 kg $N-P_2O_5-K_2O$/ha...$N:P_2O_5:K_2O$ ratio of 1: 0.48: 0.6 (**Table 1**). Additional K application provided no yield advantage at this site. Treatments omitting P and K produced significantly less.
2) Higher produce quality was achieved with either the OPT or +K treatments (**Table 2**). Both of these treatments had elevated vitamin C (Vc) contents. The +K treatment had noticeable higher protein and lower nitrate (NO_3-N) contents in harvested product. Again, the -P and -K treatments had a negative impact on quality.

Table 2. Treatment effects on water bamboo stem quality, Zhejiang.

Treatment	Length, cm	Width, cm	Net weight, g	Vc, mg/kg	Sugar, %	Protein, %	NO_3-N, mg/kg
OPT	18.16	2.96	50.1	85.4	2.4	14.81	35.1
+K	18.39	3.13	51.2	100.8	2.6	17.19	29.7
-P	19.15	2.87	43.8	70.6	2.4	14.75	34.5
-K	17.55	2.59	36.3	75.6	2.6	14.00	34.8

3) Economic analysis found the highest yielding treatment to be the most profitable (**Table 3**). Treatments omitting P and K were half as profitable as the OPT treatment.

The incorporation of water bamboo into the lowland rice production system has greatly increased potential productivity for local farmers. Balanced fertilization is one of the key practices needed to sustain yields, quality, and economic benefit of water bamboo production. BC

Table 3. Economic impact (US$/ha) of balanced fertilization, Zhejiang.

Treatment	Input	Output	Profit	Value-to-cost
OPT	976	3,513	2,537	2.60
+K	1,011	3,399	2,388	2.36
-P	914	2,124	1,210	1.32
-K	907	2,135	1,228	1.35

Dr. Chen is Deputy Director, PPI/PPIC China Program, Southeast Region, and Professor, Wuhan Botanical Garden, Chinese Academy of Sciences, Wuhan, 430074; e-mail: fchen@ppi-ppic.org. Dr. Jiang and Dr. Fu are with the Soil and Fertilizer Institute, Zhejiang Academy of Agricultural Sciences, Hangzhou, 310021, China.

Alfalfa Forage Production under Different Phosphorus Supply Strategies

By María A. Marino and Angel Berardo

Alfalfa is one of the most important resources for high quality forage in the Pampas region of Argentina, with 1.75 million hectares (M ha) planted. Nonetheless, its yield potential is frequently restrained by inadequate soil phosphorus (P) supply.

Soils of the Pampas, typically Mollisols, commonly present low soil P availability for crops and pastures. Alfalfa is especially affected and forage yield responses to P fertilization are widespread. Adequate P fertilization will often produce a "residual effect" and increase forage productivity beyond the year of application. A fraction of the applied P remains in the soil, and depending on the soil characteristics, converts to different organic and inorganic forms having variable availability to crops (Picone et al., 2003).

Regional information about P response and its residual effect on mixed pastures or alfalfa production is insufficient. Further study would contribute to improved alfalfa management and livestock productivity. This article summarizes research evaluating the effect of P fertilization on soil P supply and alfalfa production during a 4-year period after its application to a Mollisol located in southeastern Buenos Aires Province.

Alfalfa (variety GT 13 R Plus) was sown in autumn of 1995 on a Typic Argiudoll with 10 parts per million (ppm) Bray P-1, pH 6.2, and 6.4% organic matter. Five treatments were evaluated in an experimental design with three randomized complete blocks: 0, 25, 50, and 100 kg P/ha as triple superphosphate (0-46-0) which was surface broadcast at planting, and an annual fertilization treatment using 50 kg P/ha in the initial year followed by 100 kg P/ha in each subsequent year.

Alfalfa production has great potential in the pampas region of Argentina, but P fertilization is an important consideration.

Annual forage production, expressed as dry matter (DM), was evaluated with successive harvests at approximately 10% of crop flowering. Forage samples were collected to quantify plant P concentration (%) and crop P removal (Pr). Soil samples (0 to 15 cm depth) were collected during autumn to measure Bray P-1, before annual P fertilization. The P fertilization effect on soil P supply during the 4 years of experimentation and its relationship with forage production was described with regression analysis.

Precipitation during the four growing

P rate, kg P/ha	1995-96 DM, t/ha	1995-96 Pr, kg P/ha	1996-97 DM, t/ha	1996-97 Pr, kg P/ha	1997-98 DM, t/ha	1997-98 Pr, kg P/ha	1998-99 DM, t/ha	1998-99 Pr, kg P/ha	Accumulated DM, t/ha	Accumulated Pr, kg P/ha
0	10.0	20.4	9.1	18.3	7.6	10.9	8.2	11.4	35.0	61.0
25	14.3	32.6	11.8	27.0	9.1	14.2	10.0	14.0	45.2	87.8
50	16.0	37.1	12.9	29.1	9.3	14.3	9.0	15.0	47.3	95.5
100	20.2	49.7	15.6	40.3	11.4	18.5	11.9	17.7	59.2	126.2
50[1]+100[2]	16.9	—	15.0	42.3	14.4	32.8	15.3	30.9	61.6	—

Table 1. Forage production (DM) and P removal (Pr) on each growth period and accumulated in the 4 years of study, Buenos Aires.

[1] Applied in initial year.
[2] Applied in the remaining years.

periods (August to March) was 678, 863, 584, and 352 mm, respectively. The local average (1966 to 1994) is 608 mm.

Phosphorus Fertilization and Forage Production

Annual and accumulated forage production (**Table 1**) showed a linear increase up to the highest P rate applied (100 kg P/ha), according to the following regressions:

1st year: DM = 10,887 + 97.2 P $r^2 = 0.72$
2nd year: DM = 9,637 + 62.1 P $r^2 = 0.51$
3rd year: DM = 7,776 + 34.3 P $r^2 = 0.22$
4th year: DM = 8,351 + 33.1 P $r^2 = 0.19$
Accumulated production (1st to 4th year):
DM = 36,665 + 227.7 P $r^2 = 0.46$

Linear coefficients for these P responses indicate an initially high residual effect which decreased during the years after fertilization. The magnitude of the accumulated response (227.7 kg DM/kg P) demonstrates the importance of P fertilization for soils supporting alfalfa production in this region. Similar results were obtained in the first year of alfalfa production by Vivas and Guaita (1997) and Carta et al. (2001a). These studies dealt with regions where soil P availability was reduced due to agricultural intensification without adequate P replacement.

Despite this residual effect, the treatment supplying the highest one-time P rate (100 kg P/ha) became less productive than annual fertilization after the second year (**Table 1**). It should be noted that forage production also showed a gradual decline throughout the study years, independent of P treatment. This could be attributed to restricted soil water availability and other nutrient deficiencies such as sulfur (S) or boron (B), as was previously found in alfalfa by Fontanetto (2000) and Carta et al. (2001b).

Phosphorus fertilization increased alfalfa forage production in this Argentina study. Apparent recovery of P was high in the year of application and diminished with time.

Forage P Concentration and Recovery of Applied P

Phosphorus removal data were closely related to forage production. Forage P concentration was higher in the first and second year (from

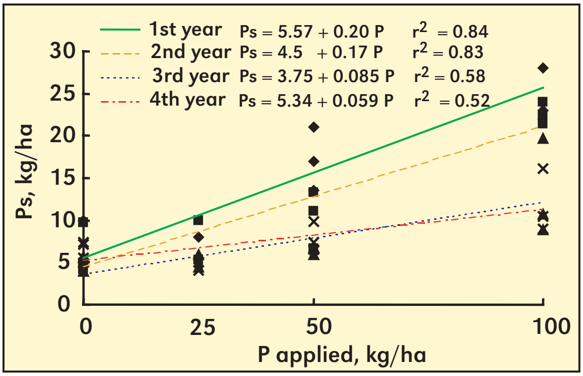


Figure 1. Relation among initial P rate and Bray P-I content (Ps) for each of the 4 years after application, Buenos Aires.

0.20 to 0.26%), and considerably lower in the third and fourth year (0.14 and 0.19%), due to lower P supplies in treatments not provided with annual P applications. As an example, respective crop removal for the P_0 and P_{100} treatments fell from 20 and 50 kg P/ha in the first year to 11 and 18 kg P/ha in the last year.

The annual fertilization regime maintained P values over 30 kg P/ha and produced steady forage P concentrations for all 4 years, ranging between 0.29 to 0.20%. Alfalfa P concentrations corresponding to the highest P rate were similar to those cited by Kelling and Matocha (1990). These elevated forage P concentrations are in turn related to enhanced forage quality, animal nutrition, and livestock productivity.

Apparent recovery of P was high in the year of application and, as was observed with P response, diminished with time. Accumulated P recovery values ranged between 65 to 100%. Results with annual crops such as wheat (Berardo et al., 1997) and mixed pastures (Berardo and Marino, 2000) were similar.

Relationship of Soil P Availability and Forage Production

Phosphorus fertilization increased soil P availability, but this effect also decreased year by year. The regression between applied P and Bray P-1 content (Ps) for each of the 4 years demonstrates the expected duration of any residual P effect (**Figure 1**). The coefficients obtained were similar to those found for mixed pastures on similar soils and climatic conditions (Berardo and Marino, 2000), but higher than those reported for pastures located on Vertic Argiudolls and Argillic Peluderts (Boschetti et al., 1996).

Alfalfa forage production was related to Ps (**Figure 2**). A Ps value near 25 mg P/kg corresponded to 90% of maximum yield. These values are slightly higher than those previously estimated for mixed pastures (Quintero et al., 1997; Berardo and Marino, 2000). The difference could be attributed to higher forage yields at this site.

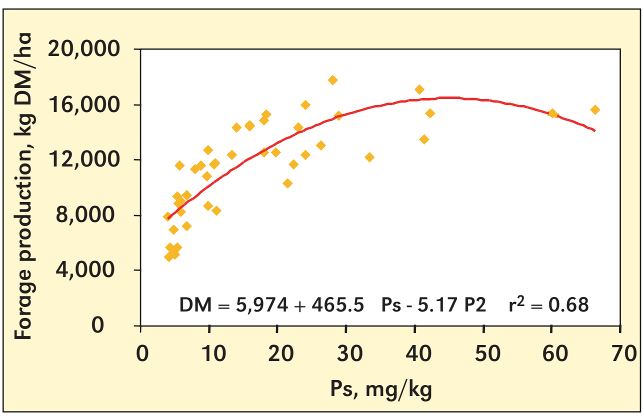


Figure 2. Relationship of Bray P-I content (Ps) and alfalfa forage production during the experimental period, Buenos Aires.

Summary

Phosphorus fertilization increased alfalfa forage production during 4 years of study with a total accumulated effect of 228 kg DM/kg P. Maximum productivity was attained in the first 2 years with the initial rate of 100 kg P/ha, but this needed to be followed by annual applications of 100 kg P/ha in the last 2 years. Phosphorus application significantly increased P plant concentration and levels of alfalfa P removal (20 to 50 kg P/ha year). Fertilization requirements for soil P replenishment will depend on harvested yield and forage P use efficiency.

Increased soil P supply, forage production, and apparent P recovery in the 4 years after P fertilization support the hypothesis of large residual effects and high P efficiency for Mollisols of the region. The relationship among soil P availability and alfalfa forage production indicates that forage production would be restricted if Ps values were below 25 mg P/kg. BC

Ms. Marino (M.Sc.) is Instructor, Production Systems, Facultad de Ciencias Agrarias (UNMdP), CC 276, 7620 Balcarce, Buenos Aires, Argentina; e-mail: mmarino@copetel.com.ar. Mr. Berardo (M.Sc.) is Professor, Soil Fertility and Management, Facultad de Ciencias Agrarias (UNMdP), CC 276, 7620 Balcarce, Buenos Aires, Argentina; e-mail: aberardo@laboratoriofertilab.com.ar.

References

Berardo, A. and M.A. Marino. 2000. I – Pasturas consociadas. Congreso Argentino de la Ciencia del Suelo. Mar del Plata.

Berardo, A., F. Grattone, R. Rizzali, and F. García. 1997. Better Crops International. Vol. 11, Issue 2, November 1997: 18-20.

Boschetti, N.G, C.E. Quintero, and R.A. Benavidez. 1996. Ciencia del Suelo 14: 20-23.

Carta, H., L. Ventimiglia, and S. Rillo. 2001a. En: L. Ventimiglia et al. (ed.). Experimentación en campos de productores, Campaña. 2000/01. UEEA INTA 9 de Julio. 9 de Julio, Buenos Aires, Argentina.

Carta, H., L. Ventimiglia, and S. Rillo. 2001b. En: L. Ventimiglia et al. (ed.). Experimentación en campos de productores, Campaña 2000/01. UEEA INTA 9 de Julio. 9 de Julio, Buenos Aires, Argentina.

Fontanetto, H. 2000. Jornadas de Intercambio Técnico de Pasturas. p. 53-65. AAPRESID. Rosario, Santa Fé, Argentina.

Kelling, K.A. and J.E. Matocha. 1990. Plant analysis as an aid in fertilizing forage crops. *In* Soil Testing and Plant Analysis. SSSA. p. 632-633.

Picone, L., E. Zamuner, and A. Berardo. 2003. Nutrient cycling in agroecosystems. 67: 225-232.

Quintero, C.E., N.G. Boschetti, and R.A. Benavidez. 1997. Ciencia del Suelo 15:1-5.

Vivas, H.S. and M.S. Guaita. 1997. Publicacion Miscelánea No. 84. EEA INTA Rafaela, Santa Fé. Argentina.

A Nutrient Decision Support System Software for Irrigated Rice

By C. Witt, T.H. Fairhurst, J.E. Sheehy, A. Dobermann, and A. Gfroerer-Kerstan

The Nutrient Decision Support System (NuDSS) for irrigated rice is part of an initiative by the Irrigated Rice Research Consortium to provide decision support on site-specific nutrient management (SSNM) in the irrigated lowlands. The software, consistent with earlier publications on SSNM, includes a handbook and practical guide.

In irrigated rice, SSNM is a plant-based approach for estimating fertilizer nitrogen (N), phosphorus (P), and potassium (K) requirements. Key principles include: identification of a suitable yield target considering the yield potential; estimation of indigenous nutrient supplies using a nutrient omission approach (nutrient-limited yield); estimation of nutrient requirements based an expected yield gain; dynamic field-specific application of fertilizer N during the growing season, including the use of a leaf color chart (LCC); and selection of P_2O_5 and K_2O rates sufficient to overcome deficiencies and avoid soil nutrient depletion. The SSNM concept has been developed and successfully tested in key irrigated rice domains of Asia and further evolved into strategies for wider-scale delivery (Fairhurst and Witt 2002; Dobermann et al., 2004; Buresh et al., 2005). SSNM in intensive rice farming is now promoted in about 20 locations in tropical and sub-tropical Asia.

This article presents the general framework for the development of SSNM recommendations and associated modules for decision support in the NuDSS software. The software adds value to existing print materials on SSNM by combining various models into one user-friendly package to assist in development of improved fertilizer strategies that aim at effective fertilizer use, high and sustainable yields, and increased farmer profit. It was developed recognizing the need for decision aids providing assistance in complex mathematical calculations that would be difficult to perform otherwise.

Based on the general framework for decision support depicted in **Figure 1**, the development of improved fertilizer recommendations may include five major steps with the following outputs.

Estimate recommendation domains and indigenous nutrient supplies. Larger areas are divided into smaller recommendation domains, which determine the required number of nutrient omission plots used to obtain average N, P, and K-limited yields (estimates of indigenous nutrient supplies) valid for the domain (Dobermann et al., 2003).

Select a yield target. Season-specific yield targets are set to be about 10% greater than currently achieved in farmer fields, but not more than 80 to 85% of the yield potential (Fairhurst and Witt, 2002).

Calculate fertilizer nutrient requirements. Calculations are based on expected fertilizer nutrient requirements of 40 to 50 kg N, 20 kg P_2O_5, and 30 kg K_2O/ton required yield increase. Requirements for P

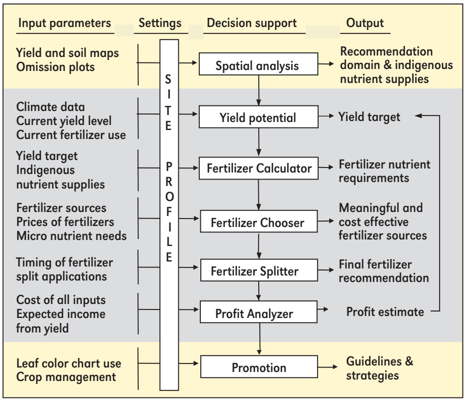


Figure 1. Flow chart of the NuDSS for irrigated rice. The gray area portrays the software modules available in the NuDSS software.

and K are adjusted using an input-output balance to prevent soil nutrient depletion due to removal with grain and straw (Fairhurst and Witt, 2002).

Select meaningful fertilizer material. Fertilizer rates of elemental nutrients (kg/ha) are expressed in nutrient sources per local area unit to facilitate wider-scale promotion.

Obtain profit estimate. The existing practice is compared with the newly developed alternative nutrient management strategy to estimate expected profit increase (ex-ante analysis). Fertilizer strategies are adjusted depending on the outcome of the economic analysis.

Simple guidelines and strategies for promotion. Where farmer fertilizer use is inadequate, it may be most effective and economic to develop, evaluate, and locally adapt improved fertilizer recommendations through farmer participation and then promote new guidelines in suitably large areas including guidelines for further adjustments. The NuDSS software aims to facilitate this process.

The NuDSS Software

NuDSS is a generic decision support system for irrigated rice capturing the most important cropping conditions in tropical and sub-tropical Asia. The underlying principles of plant nutrition are valid for all modern, high-yielding rice varieties with a harvest index of about 0.50 kg/kg. Crop- and site-specific conditions are specified in a general settings menu, including guidelines for local adaptation when conditions divert from the standard situations. The software has a built-in database for information such as default values for fertilizer sources, nutrient concentrations, and prices. NuDSS provides the option for printing user-customized reports and includes four major modules that correspond with the steps of the decision support framework (**Figure 1**).

Using NuDSS involves the following basic steps.

Settings. Select or add a Country Profile. Enter conversion factors for local currency, weight, area, and application units. Select or add available inorganic and organic fertilizer sources including cost and nutrient concentrations of each source. In the Crop Profile, select the cropping system and agronomic efficiencies.

Fertilizer Calculator. Specify or calculate the yield potential using the model developed by Sheehy et al. (2004). Calculate fertilizer requirements by specifying yield target, indigenous nutrient supply (N, P, and K-limited yield), and inputs of straw or other organic nutrient sources. Enter values for the farmers' fertilizer practice for comparison. The data entry mask of the Fertilizer Calculator is shown in **Figure 2**.

Fertilizer Chooser. Select all or specific fertilizer sources of interest. Or enter minimum amounts of a fertilizer source that must be applied. Run a solver routine to identify the least costly combination of selected fertilizer sources that matches the target recommendation rates. Evaluate different options with fertilizer sources.

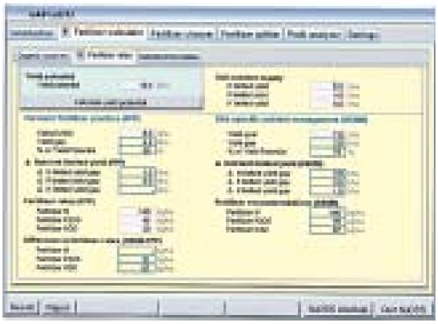


Figure 2. The NuDSS software module for calculating fertilizer N, P_2O_5, and K_2O rates.

Fertilizer Splitter. Define or select a pre-defined splitting pattern for application suitable for the specific cropping season. Choose the fertilizer source that will provide needed nutrients.

Profit Analyzer. Enter paddy farm gate price, and costs for fertilizer, materials, labor, and other costs. View results of the gross margin analysis, distribution of cost centers, and the differences in costs and net profit between farmers' practice and the improved practice (SSNM).

The primary target audiences of NuDSS are intermediary technology transfer agents, i.e. extension staff, members of cooperatives or NGOs, and private sector agronomists engaged in the development and validation of fertilizer strategies tailored to local conditions and farmers' needs. Integrating agronomic and economic aspects of nutrient management make NuDSS a powerful tool in teaching and research.

The software, a tutorial, and background information on the principles of site-specific nutrient management are available free of charge for download at the websites of the Southeast Asia Program of PPI/PPIC-IPI >**www.seap.sg**< and the International Rice Research Institute (IRRI) >**http://www.irri.org/science/software**<. BC

Dr. Witt is Director, PPI/PPIC-IPI Southeast Asia Program, Singapore, e-mail: cwitt@seap.sg. Dr. Fairhurst is Group Agriculturist, Pacific Rim Palm Oil Pte Ltd, Singapore, e-mail: tfairhurst@prpol.com. Dr. Sheehy is Senior Scientist, International Rice Research Institute, Philippines, e-mail: j.sheehy@cgiar.org. Dr. Dobermann is Professor, University of Nebraska; e-mail: adobermann2@unl.edu. Mr. Gfroerer-Kerstand is Director, PT Agrisoft-Systems Indonesia, e-mail: armin@agrisoft-systems.de.

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References

Buresh R.J., C. Witt, S. Ramanathan, B. Mishra, B. Chandrasekaran, and R. Rajendran. 2005. Site-specific nutrient management: Managing N, P, and K for rice. Fert.News. 50(3):25-28.

Dobermann, A., C. Witt, S. Abdulrachman, H.C. Gines, R. Nagarajan, T.T. Son TT, P.S.Tan, G.H. Wang, N.V. Chien, V.T.K. Thoa, C.V. Phung, P. Stalin, P. Muthukrishnan, V. Ravi, M. Babu, G.C. Simbahan, and M.A. Adviento. 2003. Soil fertility and indigenous nutrient supply in irrigated rice domains of Asia. Agron.J. 95:913-923.

Dobermann, A., C. Witt, and D. Dawe. eds. 2004. Increasing the productivity of intensive rice systems through site-specific nutrient management. Enfield, NH (USA) and Los Baños (Philippines): Science Publishers, Inc., and International Rice Research Institute (IRRI). p 1-420.

Fairhurst, T.H. and C. Witt. editors. 2002. Rice: A practical guide to nutrient management. Singapore and Makati City: Potash & Phosphate Institute/Potash & Phosphate Institute of Canada (PPI/PPIC) and International Rice Research Institute (IRRI). p 1-89.

Sheehy, J.E., S. Peng, A. Dobermann, P.P. Mitchell, A. Ferrer, J. Yang, Y. Zoue, X. Zhong, and J. Huang. 2004. Fantastic yields in the system of rice intensification: fact or fallacy? Field Crops Res. 88:1-8.

Diagnosing Potassium Deficiency and Maximizing Fruit Crop Productivity

By K.N. Tiwari

The potassium (K) requirement of fruit crops is particularly high. In contrast, however, the use of K fertilizers in Indian agriculture/horticulture is negligible. Appearance of K deficiency symptoms in fruit crops of India is becoming a common field problem. This article will serve as a diagnostic tool for K management in fruit crops.

India's wide range of agro-climatic zones provides a tremendous scope and potential for cultivation of a diverse group of fruit crops. Unfortunately, this potential has not yet been realized. There is a large gap between potential yields and actual yields harvested by farmers. For most fruit crops, yields realized are less than 50% of the easily achievable yield and 26% of the potential yield. India's current productivity of fruit crops is quite low (11.9 t/ha) as compared to the world average of over 25 t/ha. Of the various reasons responsible, inadequate and unbalanced nutrient use seems to be most important.

A wide gap also exists between domestic demand and supply for fruits, and this gap can be bridged by increasing productivity – at least equal to the extent possible through area expansion. Current fruit production (2003) is estimated at 45 million metric tonnes (M t) (**Table 1**). India's fruit requirement for 2025 is estimated to be 120 M t. These production and productivity targets can be achieved only if modern intensive horticulture is practiced using most recent technologies, including integrated nutrient use.

Mango: Old leaves show chlorosis and scorching of the tips of older leaves, spreading further towards margins.

The symptoms of K deficiency are often seen in fruit crops grown in India. Unfortunately, they go unattended because of lack of awareness to identify problems in the field. This article explains the diagnosis of K deficiency in fruit crops to ensure correct fertilization for high yield and top quality.

India's wide range of fruit crops collectively contribute to a large variation in nitrogen (N), phosphorus (P), and K removals (**Table 2**). Litchi will commonly remove the most N (194 kg N/ha), grapes remove the most P (48 kg P_2O_5/ha), and banana the most K (568 kg K_2O/ha). An average 11.9 t per ha fruit crop removes 91 kg N/ha, 23 kg P_2O_5 /ha, and 153 kg K_2O/ha—an $N:P_2O_5:K_2O$ ratio of

Table 1. Area, production, productivity (2002-03), and potentials for fruit crops, India.

Crop	Area, 000 ha	Production, 000 t	Productivity, t/ha Actual	Potential	Percent diff.
Mango	1,623	12,733	7.8	20	39
Banana	475	13,304	28.0	60	47
Citrus	563	5,677	10.1	30	34
Apple	193	1,348	7.0	30	23
Guava	155	1,793	11.6	20	58
Pineapple	80	1,172	14.7	85	17
Sapota	84	913	10.9	80	14
Papaya	68	2,147	31.6	80	40
Grapes	52	1,248	24.0	40	60
Litchi	54	476	8.8	20	44
Others	441	4,391	11.9	46	26
All India	3,788	45,203	11.9	46	26

Table 2. Nutrient removal by India's major fruits crops

Crop	Removal, kg/t of produce N	P_2O_5	K_2O
Mango	6.7	1.7	6.7
Banana	5.6	1.3	20.3
Citrus	9.0	2.0	11.7
Apple	3.3	1.5	6.0
Guava	6.0	2.5	7.5
Pineapple	1.8	0.5	6.3
Sapota	1.6	0.6	2.1
Papaya	2.8	0.8	2.3
Grape	8.0	2.0	9.0
Ber	4.0	1.8	6.3
Passion fruit	4.0	1.0	5.0
Litchi	22.0	3.5	29.0
Mean	6.2	1.8	9.4

100:29:152. Thus, the average uptake of K in contrast to N is 1.5 times larger.

Continued nutrient depletion has resulted in many soils being re-categorized as medium or lower in K fertility status where earlier they were classified as high or medium. Economic responses to applied K on soils having low and medium K fertility status are common. Sustained production in high K soils is also ensured with application rates designed to maintain soil fertility at an advantageous level.

Mango, banana, citrus, guava, papaya, grapes, and pineapple account for the major area and production of fruit crops grown in the tropics and subtropics. The majority of these fruits are marketable as fresh for domestic consumption and less than 1%...mainly mango, pineapple, and citrus...are marketable in other forms for export and domestic consumption. Fruit size, appearance, and color largely determine consumer acceptance. Factors such as fruit recovery, aroma, and taste play a secondary role in acceptability at market.

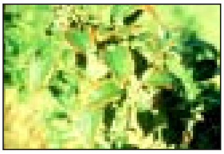
Citrus: Chlorosis and scorching of the tips of older leaves.

Despite the large production of fruits, fixed standards for quality parameters in most fruit crops are lacking. However, examples of increasing quality consciousness in fruit trade do exist. Maharashtra State Grape Growers Association has developed strict quality controls for grapes wherein quality and price are largely determined by shape, size of bunch (300 g), and total soluble solids (TSS) content of berries (22%). In Gujarat (Balsar District), a 10 kg box of Sapota containing 90 fruits is worth double the price compared to crops of lower weight. Farmers producing crops with bunch weights in the range of 15 to 17 kg receive double the price of bunches below 10 kg weight.

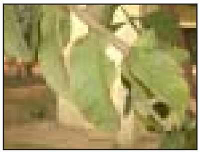
Many factors influence fruit quality and K nutrition is among the most important. Fruit size, appearance, colour, soluble solids, acidity, vitamin content, taste, as well as shelf-life are significantly influenced by adequate supply of K. These characteristics are affected by photosynthesis, translocation of photosynthates, regulation of stomata, activation of enzymes, and many other processes. Potassium's role in water regulation of the plants and tolerance to environmental stresses such as drought, excess water, wind, and high and low temperature is related to productivity of the trees and quality of the fruits. Widespread use of N fertilizers alone leave plants overly susceptibile to

With increasing severity of K deficiency, the following symptoms develop:

- Reduction in growth rate and vigour.
- Darkening of the leaves.
- Appearance of white, yellow, or orange chlorotic spots or stripes on older leaves, starting from the leaf tips and margins. In some species, irregularly distributed chlorotic spots begin appearing near the leaf tip. The base of the leaf usually remains dark green.
- Chlorotic areas become necrotic. The tissue dies and leaves dry up.
- The symptoms spread to younger leaves and risk of stress-induced death increases.
- Drought resistance declines.
- Roots are poorly developed and are often affected by rot.
- Disease incidence increases and crop quality is severely reduced.



Apple (left), Guava (right): Acute K deficiency; chlorosis and scorching of the margins of older leaves.



Banana: Chlorosis and scorching starting from the margins of older leaves.

the effects of diseases and pests – a scenario countered by optimum K nutrition. Other beneficial effects of K include high juice content, improved oil content of kernels, high vitamin C content, uniformity and acceleration of ripening of fruits, and resistance to bruising or physical breakdown during shipping and storage.

Potassium Deficiency Symptoms

Growing plants which contain inadequate K exhibit certain signs of such a deficiency. The first sign is a reduction in the growth rate of plants (which become stunted) and leaf color becomes darker than normal. Clearer deficiency symptoms start to appear as the plant grows to maturity. As K is highly mobile within the plant, the first symptoms appear on older leaves. The sequence in the development of deficiency symptoms is nearly identical with all plants, although particular species, cultivars, or clones may exhibit characteristic differences. In all cases, symptoms start from the distal part (tip) of the leaf. The base of the leaf usually remains dark green. Long before symptoms of K deficiency become visible, significant losses in both crop yield and crop quality have occurred. Apart from the above "typical" symptoms, other symptoms may occur as a result of imbalance of K with other nutrients, N and calcium (Ca) in particular. Symptoms similar to K deficiency can occur due to salt injury, fungal attack, faulty in-crop spray damage, etc. When diagnosing K deficiency in the field, the above conditions should be checked and eliminated as possible causes of confusion and incorrect diagnosis.

Orange: Chlorosis starting from the tips, spreading inside of older leaves.

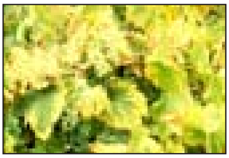
Pineapple: Chlorosis and necrosis of tips; dead tissues and withering of older leaves in acute K deficiency.

Conclusion

The need and importance of K fertilization for harvesting high yields and superior quality produce is greater now than ever before. It can be put into practice by at least using the presently recommended K application rates along with other required nutrients as prescribed by soil test. At the same time, steps must be initiated to take a fresh look at the current approach and methodology for making K recommendations which are often proved inadequate for maximum economic yields. These should primarily address the need for using soil- and crop-specific limits of available soil K while making K recommendations and also provide recommendations for above average farmers who are not satisfied with moderate yield levels. BC

Dr. Tiwari is Director, PPI/PPIC-India Programme, Gurgaon, India; e-mail: kntiwari@ppi-ppic.org.

Papaya: Chlorosis and necrosis of tips and margins; withering of old leaves in acute K deficiency.



Grape: Acute K deficiency; Chlorosis and scorching of the margins of older leaves.

May You Live in Interesting Times

An often-quoted phrase, sometimes found in fortune cookies, says: "May you live in interesting times." While that may not rank up there with "You will find a pot of gold in your corn field" or "Your pile of rocks will turn to diamonds", it may be just as valuable in some respects.

Consider your fate if you lived in an era when there was no change…no new innovations in science or industry, no breakthroughs in medicine or health care, no new discoveries in space, no progress in crop yields or agricultural technology.

While many people these days think the rate of change in some aspects of civilization is too rapid or too extreme, perhaps the other end of the spectrum would be worse. If each day went by the same as the day before and there was no motivation for progress, the world might fall into a modern reincarnation of the Dark Ages.

Whether you are 20 years old, 50, or 100, think of the changes in your own lifetime. While there is always a thread of nostalgia to go "back to the good old days", were they really that great after all? In the perspective of history, most people would have to agree that we are living in "interesting times." Given a choice, how many people would actually choose to live in another period in history?

For those who work in the field of agriculture and the crop nutrients industry, the challenges of managing resources and adapting to the uncertainties of weather, markets, politics, and numerous other factors have always kept the times interesting. Each new step forward in plant breeding and biotechnology, each new crop disease threat, and each new shift in priorities of the world's population…all have the potential to open doors to expanded opportunities and production needs.

The Potash & Phosphate Institute (PPI) has been in existence for seven decades, and those 70 years would have to rate as "interesting times." The circumstances of the fertilizer industry and agricultural production have changed dramatically, yet the need for the unique programs of agronomic research and education championed by PPI are as vital as ever.

David W. Dibb
President, PPI

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