BETTER CROPS
WITH PLANT FOOD

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In This Issue...

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BETTER CROPS
WITH PLANT FOOD

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Our cover: Aerial view of fields near Nanning City, the capital of Guangi Province in China.
Photo by Dr. Svetlana Ivanova, IPNI

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Note to Readers: Articles which appear in this issue of *Better Crops with Plant Food* (and previous issues) can be found as PDF files at the IPNI website: **>www.ipni.net/bettercrops<**

Graduate Students Encouraged to Apply for IPNI Scholar Awards

The International Plant Nutrition Institute (IPNI) is offering financial awards to a limited number of graduate students in 2008. The IPNI Scholar Awards in the amount of US$2,000 (two thousand dollars) each will be conferred to graduate students in sciences relevant to plant nutrition and management of crop nutrients.

"The application process has changed for this year," notes IPNI President Dr. Terry Roberts. "The application is only available on-line. Graduate students attending a degree-granting institution located in any country with an IPNI program are eligible and encouraged to apply."

The application instructions are available at the IPNI website: **www.ipni.net/scholar**.


International Plant Nutrition Institute
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ANNOUNCEMENT
of the
International Plant Nutrition Institute (IPNI)
Scholar Awards — 2008

The IPNI Scholar Award is made directly to the student, and will be granted independent of any assistantship, scholarship, or other award that the student presently holds. No specific duties will be required of the recipient.

Graduate students who are candidates for either the M.S. or Ph.D. degree and currently attending a degree-granting institution are eligible. In the case of Ph.D. candidates, preference will be given to students who have a minimum of one-year remaining before completion of their studies. Priority will be given to the relevance of the proposed research in support of IPNI's mission. Students in the disciplines of soil and plant sciences, including agronomy, horticulture, ecology, soil fertility, soil chemistry, crop physiology, and other areas related to plant nutrition are encouraged to apply. Winners of the IPNI Scholar Award are not eligible for reappointment; the awards are for one time only.

In order to complete the application process, candidates will need the following:

1. Electronic copy of transcripts of all college work, including cumulative and final grade average records (GPA and percentile).
2. Electronic copy of three letters of support, one of which should be from the major professor. Letters must be signed and written on official letterhead, and must include the phone number and e-mail address of the letter writer.
3. A description of the focus of the applicant's thesis or dissertation research presented in a manner that will permit evaluation of its originality, depth, and scope, plus innovative approaches and relevance to IPNI's mission.
4. Applicants will be asked to briefly describe any honors or awards received, employment, career goals, and other activities.

Applicants will be required to upload the electronic copy of the transcripts and support letters during the on-line application process. Further instructions are provided at the website.

Applications must be completed by June 30, 2008. Announcement of the Scholar Awards will be made in September and checks will be presented to the winners as soon as practical thereafter. BC

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9th International Conference on Precision Agriculture Set for July 20-23 in Denver

The 9th International Conference on Precision Agriculture (ICPA) is set for July 20-23, 2008, in Denver, Colorado. Dr. Rajiv Khosla of Colorado State University will serve as Conference Chairperson for the event, which was previously located at the University of Minnesota-St. Paul. Dr. Harold Reetz of IPNI/FAR serves on the Organizing Committee, along with Dr. Dwayne Westfall of Colorado State University and Mr. Quentin Rund of PAQ Interactive. The ICPA is oriented primarily to research progress, and facilitates interactions among scientists, producers, technology company representatives, equipment manufacturers, input dealers, agronomic consultants, software developers, educators, government personnel, and policymakers. Find out more at the ICPA website: **www.icpaonline.org**. BC

Starter Fertilizer for Delayed-Flood Rice — Agronomic Effects

By Tim Walker, Rick Norman, Brian Ottis, and Jason Bond

Results from this study indicate that starter N applications when applied to semi-dwarf cultivars planted on clay soils in the Mississippi River Alluvial Flood Plain can increase seedling plant height and moderately increase rice grain yield.

In recent years, the *sd1* semidwarf gene has been used extensively in U.S.A. public rice (*Oryza sativa* L.) breeding programs largely because the semidwarf plant type allows for greater yields through higher N fertilization rates while reducing the susceptibility to lodging (McClung, 2003). Because of these characteristics, semidwarf cultivars have increased in popularity in the southern U.S.A. rice-growing region, are planted on a large percentage of the acreage, and have contributed to increased grain yield in the last 20 years (**Figure 1**). Because of their shorter mesocotyls, emergence and seedling growth rates of semidwarf cultivars can be lower compared to taller cultivars (Turner et al., 1982). This difference can be further exacerbated when rice is planted on alluvial clay soils, which represent the majority of rice acreage in Mississippi and a growing percentage of acreage in Arkansas and Missouri. Clay soils have less N-supplying capacity compared to coarser-textured soils such as silt loams (Trostle et al., 1998).

Nutrient availability and uptake, as well as weed control, are facilitated by the flooded soil environment (Norman et al., 2003; Kendig et al., 2003). In addition, thermal time (degree days) greatly determines rice plant development (Moldenhauer and Gibbons, 2003). Therefore, practices that encourage biomass production in the seedling and early vegetative stages are needed so that rice is grown in an upland environment for a minimum number of days.

Starter fertilizer sources have proven to be beneficial in increasing early-season vegetation and sometimes yield in corn, cotton, and soybean (Vetsch and Randall, 2000; Bednarz et al., 2000; Osborne and Riedell, 2006). Therefore, studies

Rice plot harvest using a small-plot combine at the Delta Research and Extension Center near Stoneville, Mississippi.

to investigate starter fertilizer in rice were warranted. The specific objective of this study was to determine the potential for using starter N fertilizer to increase seedling rice growth and grain yield for semidwarf cultivars planted in clay soils in the southern U.S.A. rice production area.

An experiment was conducted in 2005 and in 2006 at the Delta Research and Extension Center in Stoneville, Mississippi, and at the Northeast Research and Extension Center in Keiser, Arkansas, and in 2006 at the University of Missouri-Columbia Lee Farm, near Portageville. Sharkey clay (very-fine, smectitic, thermic Chromic Epiaquerts) soil was present at each location and specific soil chemical properties are listed in **Table 1**. Twelve total treatments that consisted of combinations of starter N source and preflood N rate were evaluated. The starter N sources…AMS, 21% N; DAP, 18% N; and urea, 46% N…were applied to 2-leaf Cocodrie rice cultivar at the

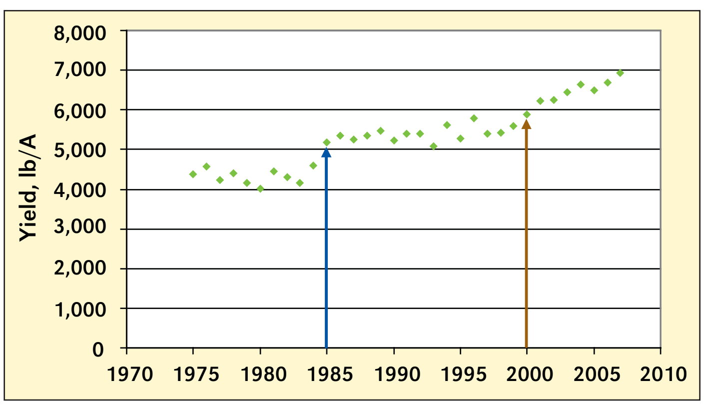

Figure 1. Rice grain yield by year from 1975 to 2007 for southern U.S.A. rice-producing states, including Arkansas, Louisiana, Mississippi, Missouri, and Texas. 'Lemont', released by Texas in 1985, was one of the first semidwarf cultivars planted across large acreages in the south. Since its release in 2000, Cocodrie has been one of the most popular semidwarf cultivars planted in the southern U.S.A. rice-producing area.

Bluebonnet is a tall cultivar released by Texas in 1944.

Abbreviations and notes for this article: N = nitrogen; AMS = ammonium sulfate; DAP = diammonium phosphate; PF = preflood; PE = panicle emergence; OM = organic matter; TDM = total dry matter; TNU = total N uptake.

Table 1. Selected soil chemical properties (pH, organic matter, and clay content) and pertinent agronomic dates for studies conducted in Arkansas, Missouri, and Mississippi.

State	Year	Soil pH[†]	OM, %	Clay	Planting date	Starter N application date	Preflood N application date	Harvest date
Arkansas	2005	6.5	1.6	53	20 Apr	17 May	8 Jun	22 Sep
	2006				24 Apr	16 May	15 Jun	15 Sep
Missouri	2006	6.0	3.4	58	23 Apr	15 May	5 Jun	6 Sep
Mississippi	2005	8.0	2.2	60	3 May	18 May	6 Jun	15 Sep
	2006				9 May	31 May	10 Jun	20 Sep

Soil pH measured in a 1:2 soil/water ratio.

Dr. Tim Walker collects plot notes (heading dates) in rice grown at Delta Research and extension Center near Stoneville, Mississippi.

rate of 20 lb N/A. A control treatment receiving no starter N was also included. Plots were flush-irrigated to incorporate fertilizer treatments within 3 days after application. Preflood N rates (90, 120, and 150 lb N/A) as urea were applied to 5-leaf rice within 3 days prior to flood establishment. Prior to the N application PF at the 5-leaf growth stage, plant heights were measured from 5 individual plants randomly selected from each plot, including the no-starter treatment. Additionally, total aboveground biomass was harvested from 3 linear feet of row, dried at 140°F for 72 hours, weighed for total dry matter (TDM), and then processed and analyzed for total N content. Total dry matter and total N content were also determined at panicle emergence as previously described. Plots were threshed when grain moisture reached 16 to 20%, and grain yields were standardized to 12% moisture content. Response variables are reported as the means of the 5 site-years.

Plant height measured at the 5-leaf growth stage was affected by starter N source. Ammonium sulfate and DAP produced plant heights that were approximately 14% greater than when no starter was applied (**Table 2**). Though not significant, TNU and TDM tended to be greater when 20 lb N/A was applied as a starter (**Table 2**). Starter N did not affect TDM and TNU when measured at PE. However, rice grain yield was affected by starter N source. Modest grain yield increases were observed when AMS and DAP were applied as a starter compared to when no starter was applied (**Table 3**).

Total dry matter, TNU, and grain yield were all affected by PF N rate. Yield and TDM were greatest when at least 120 lb N/A was applied PF, whereas TNU increased with increasing PF N rate (**Table 4**).

These data suggest that plant height at the 5-leaf stage can be increased with an AMS or DAP application on 2-leaf rice at a rate of 20 lb N/A. This plant height increase can have positive management implications. First of all, greater plant height will allow for earlier flood establishment. The flood provides growers the opportunity to potentially decrease the number of herbicide applications. Furthermore, flooding earlier increases the number of days rice vegetative growth occurs in a flooded environment which has positive implications on nutrient availability and uptake. Starter N in the form of AMS and DAP also increased grain yields when compared to no starter application. Future research should address starter fertilizer rates, combinations, and placement as research in

(continued on page 7)

Table 4. Total dry matter and total N uptake at panicle emergence, and grain yield as affected by preflood N rate averaged across starter N sources.

Rate, lb N/A	TDM[1], lb/A	TNU, lb N/A	Yield, lb/A
90	9,035 b	134 c	7,583 b
120	9,803 a	153 b	8,102 a
150	10,105 a	176 a	8,340 a

[1]Means in the same column followed by a different letter are different at $p \leq 0.05$.

Table 2. Plant height, total N uptake, and total dry matter measured at the 5-leaf stage as affected by starter N fertilizer source.

Starter	Height,[1] in.	TNU, lb N/A	Biomass, lb/A
AMS	9.3 a	6.7	168
DAP	9.4 a	6.6	165
Urea	8.9 ab	6.2	163
None	8.1 b	5.4	136
		NS	NS

[1]Means in the same column followed by a different letter are different at $p \leq 0.05$.

Table 3. Grain yield as affected by starter N source averaged across preflood N rates.

Starter	Yield,[1] lb/A
AMS	8,117 a
DAP	8,076 ab
Urea	7,941 bc
None	7,899 c

[1]Means in the same column followed by a different letter are different at $p \leq 0.05$.

Cocodrie is a semidwarf cultivar released by Louisiana in 2000.

Maximizing Irrigated Soybean Yields in the Great Plains

By W. B. Gordon

Several years of irrigated field research in north central Kansas clearly demonstrated the importance of complete and balanced nutrition in the production of high yield corn (Gordon, 2005). However, fertilization of soybeans in a common corn/soybean rotation has traditionally been secondary to corn fertilization, as the crop is usually left to scavenge nutrients remaining after corn. This study was started in 2004 as an expansion of the original corn research to determine the benefit of direct fertilizer application to sprinkler-irrigated soybeans. It has shown that the addition of P and K can have a significant impact on soybean yield, with 4-year average increases due to P and K as high as 34 bu/A. This experiment also demonstrated that Mn can impact soybean production in high yielding environments.

Analysis of corn yield data from hybrid performance tests in north central Kansas show that corn yields have increased by an average of nearly 2.5 bu/A/year. Nationally, trends are similar. Soybean yield trends have also been on an upward swing, but the rate of increase is less than 1 bu/A/year. This increase can be attributed to genetic advances among other factors. Genes imparting herbicide resistance have been incorporated and many advances in disease resistance have occurred. Effective fungicide and insecticide seed treatments are now available for use in soybeans.

Despite the many advances, soybean yields have not improved as dramatically as corn. Fertility issues could be among the factors limiting yield improvement. Typically in a corn-soybean rotation, fertilizer is only applied during the corn phase of the rotation, despite the fact that on a per bushel basis soybeans remove nearly twice as much P and almost five times as much K as corn. With greater corn yield, more nutrients are removed and less is left over for the following soybean crop. To capitalize on genetic improvements in yield and technical advances in production, levels of plant nutrients must not be limiting. Other production practices such as plant population and row spacing may interact with fertility management to influence crop yields. The objective of this experiment was to develop cropping systems and fertility practices that will maximize yield of irrigated soybeans.

Procedures

The experiment was conducted on a Crete silt loam soil at the North Central Kansas Experiment Field, located near Scandia. Treatments included soybean planted at two row spacings (30 and 15 in. wide) and two plant populations (150,000 and 225,000 plants/A). Fertility treatments consisted of a low P application (KSU soil test recommendations would consist of 30 lb P_2O_5/A at this site), low P-low K, low P-high K, high P-high K, N-P-K, and an unfertilized check plot. Phosphorus application rates were 30 or 80 lb P_2O_5/A, and K treatments were 80 or 120 lb K_2O/A. The N-P-K treatment consisted of application of 20 lb N, 80 lb P_2O_5 and 120 lb K_2O/A. A treatment was added in 2005 that included the same rate of N, P, K plus 5 lb/A Mn. Soil test values for the experimental area were: pH, 7.1; Bray-1 P, 12 ppm (low); and exchangeable K, 250 ppm (very high). The K source used was KCl and the P source was triple super phosphate. Fertilizer was broadcast in mid-March each year. The previous crop was corn. Each year, corn received 180 lb N/A and 40 lb P_2O_5/A. Whole plant soybean samples were taken at full-bloom for nutrient analysis. Plant heights were taken just before harvest. Whole plants were taken from a 10 ft. (3-meter) length of row at maturity for yield component analysis. Seed weight was determined from seed samples retained at harvest. The soybean variety Asgrow 3305 was planted in mid May each year. Soybeans were sprinkler irrigated, receiving an average of 8 in. of irrigation water during the growing season.

Abbreviations and notes for this article: N = nitrogen; P = phosphorus; K = potassium; Mn = manganese; ppm = parts per million.

Soybean yield responded to P and K fertilizer application in irrigated plots.

Results

In no year of the experiment did increasing plant populations or reducing row spacing result in any increase in yield (**Table 1**). In 2004, increasing plant population in narrow rows

Table 1. Soybean yield as affected by row spacing and plant population (average over fertility treatments) 2004-2007.

Row space	150,000 plants/A	255,000 plants/A
	------------- yield, bu/A -------------	
30 in.	78.2	77.6
7.5 in.	78.4	76.6
LSD (0.05) =NS*		

* Not significant at the 0.05 level of probability.

Table 2. Fertility effects on soybean yield, and whole plant tissue P and K concentration at full-bloom, 2004-2007 (average over row spacing and plant population).

Treatments	Yield, bu/A	Whole plant P	Whole plant K
		----------- % -----------	
Check	50.3	0.222	2.61
Low P	68.8	0.245	2.59
Low P-Low K	77.8	0.248	2.99
Low P-High K	80.4	0.246	3.41
High P-Low K	84.7	0.292	2.97
High P-High K	84.8	0.300	3.39
N-P-K	84.9	0.294	3.42
LSD (0.05)	4.1	0.019	0.13
CV%*	4.2	5.1	4.9

* Coefficient of variation.

In 2 of the 3 years Mn was applied, average yield increase was 4.9 bu/A.

Table 3. Fertility effects on soybean yield components and plant height, 2004-2007 (average over row spacing and plant population).

Treatments	Seed number per ft.^{2}	Seed per pod, number	Seed size, grams/100 seed	Plant height, in
Check	390	1.6	10.9	23.7
Low P	485	2.2	11.4	27.2
Low P-Low K	570	2.8	12.3	28.3
Low P-High K	614	2.9	13.5	28.4
High P-Low K	660	2.9	13.6	29.3
High P-High K	661	2.9	13.2	29.6
N-P-K	660	2.9	13.8	29.9
LSD (0.05)	23	0.9	0.5	1.1
CV%	12	8.1	4.3	2.6

* Coefficient of variation.

actually reduced yield. When averaged over all 4 years of the experiment, row spacing or plant population did not affect yield of soybean, nor was there a significant interaction among the three factors in the experiment

Soybean yield did respond to fertilizer application. Addition of 30 lb P_2O_5/A resulted in a 4-year average yield increase of over 18 bu/A (**Table 2**). Applying 80 lb P_2O_5 with 60 lb/A K_2O increased yield by 34 bu/A over the unfertilized check plot. Applying additional K or adding N to the mix did not increase yields. Addition of P and K fertilizer significantly increased soybean tissue nutrient concentration at the full bloom stage of growth. Addition of fertilizer increased the number of seed, number of seed per pod, and weight of seed as well as plant height (**Table 3**). Direct application of P and K fertilizer is crucial in maximizing performance and yield of irrigated soybean.

In 2 of the 3 years that the Mn treatment was included in the experiment, Mn applied with N, P, and K resulted in an increase in soybean yield over the same treatment without Mn. Average yield increase was 4.9 bu/A in those 2 years. Manganese application can fit in a fertility program designed for maximum soybean yield. BC

IPNI/FAR Proj. No. KS-33F

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Reference

Gordon, W.B. 2005. *Better Crops*. Vol. 89, No. 2. pp. 8-10.

Delayed-Flood Rice…from page 5

other crops suggest that lower N rates can be used and still obtain increased early-season vegetative growth and grain yield (Vetsch and Randall, 2000; Kaiser et al., 2005). Finally, the recovery efficiency of starter N in rice is not well understood. Therefore, research is needed to address the dynamics of recovery of starter N applications in a delayed-flood rice production system. BC

Dr. Walker (e-mail: TWalker@drec.msstate.edu) and Dr. Bond are with Mississippi State University – Delta Research and Extension Center, Stoneville. Dr. Norman is with the University of Arkansas, Fayetteville. Dr. Ottis is with RiceTec, Inc., Sikeston, Missouri.

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Potassium Unlocks the Potential for Hybrid Rice

By S.K. Pattanayak, S.K. Mukhi, and K. Majumdar

Researchers adjusted the K application rate within a soil test-based fertilizer recommendation for hybrid rice. Adequate K input was responsible for a 6 t/ha grain yield response and lifted the potential for a two crop system yield to near 14 t/ha – a vast improvement over common farm practice, which struggles to achieve one-third of this level of productivity.

Nearly one-third of the rice produced in India comes from within the four East Indian states of West Bengal, Bihar, Orissa, and Assam. As such, East India is of critical importance with regard to food security in India. Rice is by far the dominant cereal in the region. In Orissa, the crop contributes to about 84% of all food grains grown. Orissa itself produces about 25% [6.5 million metric tons (M t) in 2004-05] of the region's rice stocks from a 4.5 M ha area. However, average productivity in Orissa is low at 1,450 kg/ha.

Inadequate and unbalanced nutrient use is one of the major factors responsible for low crop productivity in Orissa. Average fertilizer consumption ($N+P_2O_5+K_2O$) in Orissa's rice crops is also low at 47 kg/ha, much below average NPK removal by rice (160 kg/ha). Soil K status within many districts of the state is medium. However, long-term soil K fertility assessment within India has clearly shown that medium fertility status soils fall quickly to the low category if K application is inadequate. The speed and magnitude of soil K depletion varies according to cropping intensity. The average rate of K application in the state is only 7 kg/ha — about 15% of the total K removed by a single crop of rice. Thus, large negative K balances extend throughout much of the state, which is one of the most important reasons for low rice productivity.

Hybrid rice varieties were introduced to the region to augment the rice production scenario. However, an inadequate nutrient management strategy failed to produce the desired result. The cultivation of hybrids using nutrient rates applicable to 'high yielding' varieties (HYV) has failed to achieve expectations for higher yields. Hybrid varieties have higher yield potential, but require much higher quantities of applied nutrients compared to HYVs. The present study was initiated to evaluate the effect of soil test-based fertilizer recommendation on hybrid rice yield. Focus was given to the impact of alternative K application rates used within the proposed recommendation.

Field experiments were conducted near Bhubaneswar, Orissa, for two consecutive cropping seasons at a site with an acid Inceptisol soil. Soil samples were randomly collected (0 to 15 cm depth) for analysis and a yield target-based recommendation was developed following Agro Services International (ASI) analytical methods (Portch and Hunter, 2002). The experiment was laid out in a randomized block design with 12 treatments and three replications. The treatments were based on the full soil test-based fertilizer recommendation of 290 kg N, 170 kg P_2O_5, 180 kg K_2O, 1 kg B, 7 kg Zn, and 4 kg Cu. Seven treatments comprised of increasing K application rates are reported in this paper. These treatments included: T_1, zero fertilizer (control); T_2, ASI recommendation without K; T_3, ASI with 25% of the recommended K rate; T_4, ASI with 50% K; T_5, ASI with 75% K; T_6, ASI with 100% K; T_7, 150% of NPK plus recommended rates of B, Cu, and Zn.

Uniform cultural practices and plant protection measures were used within all treatments. A blanket dose of 5 t/ha of farmyard manure and 1,800 kg/ha of lime was applied to all treatments, except the zero fertilizer control. Lime was applied two days before transplanting. The basal fertilizer application included 25% of the N and K, 50% of the P, and 100% of the B, Cu, and Zn. A first topdressing occurred 21 days after transplanting and included 50% of the N, P, and K. The remaining N and K were applied at the boot leaf stage. Grain, straw, and chaff samples were analyzed for nutrient concentration and uptake at maturity following standard procedures, as were the post-harvest soil physiochemical properties and nutrient contents for each respective treatment.

The cumulative two season grain, straw, and chaff yield of hybrid rice varied between 4.9 to13.9 t/ha, 6.7 to14.6 t/ha, and 0.48 to 1 t/ha, respectively (**Table 1**). Maximum yields were observed under the full ASI recommendation. The complete exclusion of K from the recommended dose resulted in a 42% loss in grain yield and the highest chaff production. A gradual increase in K rate increased grain yield, narrowed the grain:straw ratio, and steadily improved the harvest index. The harvest index of well-managed modern high-yielding rice varieties should be near 0.5 (Khush, 1995). Application of macronutrients at 150% of the recommended rate of N, P_2O_5, and K_2O produced no extra advantage as yields dropped 35% while quantities of straw increased (**Table 1**).

Macro- and secondary nutrient uptake increased appreciably under higher rates of K application (**Table 2**). Trends in

Table 1. Effect of K rate on hybrid rice yield (two consecutive seasons).

Treatments	Grain, t/ha	Straw, t/ha	Chaff, t/ha	Grain: Straw	Harvest Index
T_1 (Control)	4.9	6.7	0.50	1:1.37	0.40
T_2 (- K)	8.0	11.5	1.00	1:1.44	0.39
T_3 (25% K)	9.3	12.0	0.90	1:1.29	0.42
T_4 (50% K)	10.7	12.3	0.80	1:1.15	0.45
T_5 (75% K)	11.2	12.9	0.70	1:1.15	0.45
T_6 (100% K)	13.9	14.0	0.48	1:1.01	0.49
T_7 (150% NPK)	9.0	14.6	0.79	1:1.62	0.37
CD[1] (0.05)	0.5	0.6	0.08	-	-

[1]Denotes critical difference.

Abbreviations and notes for this article: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Ca = calcium; B = boron; Cu = copper; Zn = zinc; C = carbon.

Table 2. Effect of K rate on nutrient uptake and recovery by hybrid rice.

Treatments	Nutrient uptake, kg/ha					Nutrient recovery efficiency, %			
	N	P	K	S	Ca	N	P	S	Ca
T_1 (Control)	83	15	148	12	28	-	-	-	-
T_2 (- K)	175	27	215	21	56	29	17	6	7
T_3 (25% K)	185	32	283	22	56	36	22	7	7
T_4 (50% K)	206	34	299	23	56	43	27	8	7
T_5 (75% K)	221	37	331	25	59	49	32	10	8
T_6 (100% K)	236	40	359	27	63	54	36	12	9
T_7 (150% NPK)	224	37	355	27	60	33	22	8	8
CD[1] (0.05)	3	2	22	4	2	-	-	-	-

[1]Denotes critical difference.

uptake indicate that hybrid rice removes much larger quantities of soil K compared to N. Apparent recovery of N, P, S, and Ca increased considerably as K application increased up to levels recommended by the soil test. Nutrient recovery declined under the treatment providing NPK at 150% of the soil test-based recommendation.

Post harvest soil properties showed a general decline in available P and K as well as organic C and an increase in soil pH (due to added lime) compared to the initial status (**Table 3**). Available P and K status declined to comparable levels across treatments with the exception of the 150% NPK treatment (T_7), which had higher soil test P and K levels – more similar to the initial values. Nutrient uptake within T_7 failed to increase significantly beyond that under the 100% NPK treatment (T_6) and the additional yet unbalanced nutrient supply within T_7 led to higher residual fertility. The general change in organic C is attributed to local field management which was conducive to enhanced C oxidization as the soil was subjected to several physical disturbances through ploughing and weeding. Also, instead of flooding or maintaining standing water, the crop was subjected to alternate wetting and drying conditions.

Table 3. Effect of K rate on post harvest soil properties and available nutrient status.

Treatments	pH	EC, dS/m	Organic C, g/kg	Available nutrients, kg/ha		
				N	P_2O_5	K_2O
Initial status	5.0	0.14	7.5	74	17	84
T_1 (Control)	4.8	0.10	5.6	36	7	23
T_2 (- K)	6.8	0.26	5.7	41	9	32
T_3 (25% K)	6.2	0.20	4.7	44	11	31
T_4 (50% K)	6.2	0.19	4.5	53	9	29
T_5 (75% K)	6.0	0.18	4.6	48	10	27
T_6 (100% K)	5.8	0.17	5.2	36	8	23
T_7 (150% NPK)	6.3	0.35	5.9	35	14	79
CD[1] (0.05)	0.3	0.01	0.21	NS	1.8	3.4

[1]Denotes critical difference.

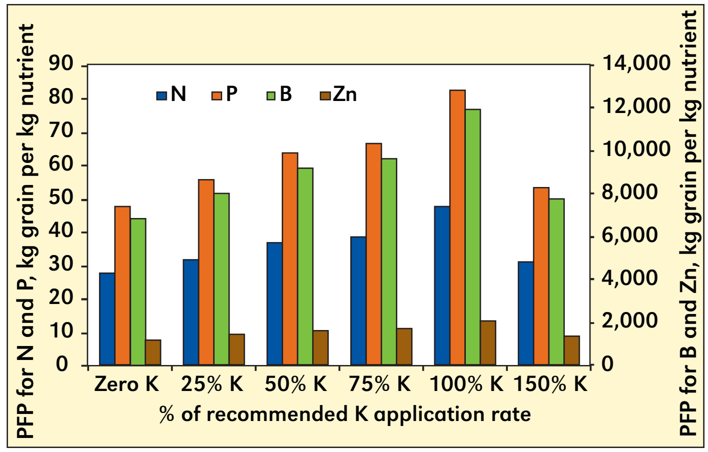

Figure 1. Effect of K rate on partial factor productivity.

Declining partial factor productivity (PFP), measured by grain output divided by the quantity of a single input factor applied (e.g., N), is a major concern in Indian agriculture. Various causes for such declines have been put forward. However, this experiment clearly shows that balanced fertilization, achieved through step-wise increases in the K fertilization schedule, produced steady improvements in PFP for N, P, B, and Zn (**Figure 1**).

Dr. Pattanayak (left) and Dr. Majumdar are shown visiting the hybrid rice trial site in Orissa.

Summary

It is essential to recognize that no nutrient works in isolation and no reason to emphasize a single factor or nutrient in high production systems. In such systems, site-specific nutrient management (SSNM) recommendations are required to fully consider crop requirement and soil nutrient supply. The principles of SSNM are to deliver amounts and ratios of nutrients based on indigenous soil nutrient supply rates, crop requirements, and a yield target, without any biased emphasis on any one particular nutrient. That, along with sound management practices and decisions, will ensure increased efficiency of nutrient use and profitability in high production systems. The magnitude of crop demand for nutrients evidenced in this study suggests a need to revise the K recommendation of hybrid rice varieties in order to match their high yield potential. BC

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Effect of Long-Term Fertilization on Wheat-Corn-Sweet Potato Rotation in the Sichuan Basin

By Wei Li, Guoxue Cai, Henglin Dai, and Shihua Tu

A multi-year study was used to develop a nutrient management scheme capable of improving yields within a prominent cropping system for the Sichuan Basin.

The Sichuan Basin is an area in southwest China which encompasses the province of Sichuan and the region surrounding the autonomous city of Chongqing. The typical farming system in the uplands of the Basin involves a rotation of wheat followed by corn and sweet potato. Wheat grows from the winter to spring, and corn and sweet potato are usually inter-planted in alleys during the summer and fall. Crop yields vary within this rotation due to weather, landscapes, soil type and fertility, crop variety, and management practices. Yields generally range between 2,250 to 4,500 kg/ha for wheat, 4,500 to 7,500 kg/ha for corn, and 3,750 to 5,000 kg/ha for sweet potato (sweet potato yield is usually converted from its fresh yield to an equivalent grain yield using a 5:1 ratio).

The two summer crops have traditionally outweighed winter wheat production in terms of economic importance. But the need for increasing amounts of animal feedstuffs is placing an ever-increasing importance on corn in the rotation. In turn, a high demand for corn grain has raised its market price and stimulated farmers' interest in corn production. The ultimate response within the region has been interest in both the expansion of area planted and enhanced yield per unit area. These circumstances have made it more important than ever to acquire science-based nutrient management which is economically sustainable and environmentally responsible.

A fixed-site experiment was established in 2001 within Liangping County, Chongqing, to document the potential for improvement in productivity and nutrient use efficiency within this crop rotation. The study site had an elevation of 450 m, annual temperatures of 17 to 18 °C, and annual precipitation of 1,100 to 1,200 mm. Soil at the site was developed from sedimentary rock, and is classified as a purple soil under the Chinese soil classification system – a prevailing soil-type throughout the Chongqing region. Soil pH, OM, ammonium-N (NH_4-N), available P, available K, extractable Ca, extractable Mg, available S, and available Zn were determined as described by Lu (2000). Results indicated that the soil was acidic with very low organic matter content, available N, P, and K (**Table 1**).

Table 1. Characteristics of tested soil.

	pH	OM	NH_4-N	P	K	Ca	Mg	S	Zn
		g/kg	- - - - - - -	- - - - - - -	- - - - - - -	mg/kg	- - - - - - -	- - - - - - -	- - - - - - -
Purple soil	5.4	4.4	20	3	62	3,818	403	75	2

The experiment, managed from 2001 to 2005, was designed as a randomized block design with 10 treatments comprised of three rates of N (two rates for wheat) and four rates of P and K (**Table 2**). Each plot had an area of 13.3 m².

Table 2. Fertilizer treatments (N-P_2O_5-K_2O kg/ha) for wheat, corn, and sweet potato.

Treatment	Wheat[1]	Corn	Sweet potato
$N_0P_0K_0$ (CK)	0-0-0	0-0-0	0-0-0
$N_1P_2K_2$	150-90-90	150-120-150	38-60-120
$N_2P_0K_2$ (OPT-P)	150-0-90	225-0-150	75-0-120
$N_2P_1K_2$	150-45-90	225-60-150	75-30-120
$N_2P_2K_2$ (OPT)	150-90-90	225-120-150	75-60-120
$N_2P_3K_2$	150-135-90	225-180-150	75-90-120
$N_2P_2K_0$ (OPT-K)	150-90-0	225-120-0	75-60-0
$N_2P_2K_1$	150-90-45	225-120-75	75-60-60
$N_2P_2K_3$	150-90-135	225-120-225	75-60-180
$N_3P_2K_2$	225-90-90	300-120-150	112-60-120

[1]For wheat, only two rates of N were compared. Thus, N_1 and N_2 are both shown as 150 kg/ha.

In the winter season, half of the field is used to grow wheat while the other half was reserved to grow corn during the spring. Sweet potato was transplanted onto the wheat stubble soon after harvest. Fertilizers included urea, single superphosphate, potassium chloride, and ammonium molybdate.

All P and K fertilizers were applied at seeding. Urea was split between a basal application (i.e., 60% of the total for wheat and sweet potato, and 30% for corn) and topdressings

Wheat plots in rotation. The fertilizer treatments (N-P_2O_5-K_2O) are 150-45-90 on the left and 150-0-90 on the right.

Abbreviations and notes for this article: N = nitrogen; P = phosphorus; K = potassium; Ca =calcium; Mg = magnesium; S = sulfur; Zn = zinc; OM = organic matter.

Corn plots in rotation.

(i.e., 40% for wheat at tillering stage, 30% and 40% for corn at the seedling and pre-silking stages, and 40% for sweet potato at tuber expansion stage, respectively). Ammonium molybdate powder was applied as a thoroughly mixed wheat seed coating. A zero fertilizer treatment was used as check (CK) to evaluate the basic soil fertility. Wheat and corn were seeded manually by hoeing and sweet potato was transplanted in alleys placed 1 m apart. Plant density was 380,000 plants per ha (30 cm × 15 cm) for wheat, 10,500 plants per ha (85 cm × 55 cm) for corn, and 23,000 plants per ha (85 cm × 25 cm) for sweet potato. Other field management was performed according to local farmer practices. Yields were calculated after each crop harvest.

The yield data suggest that both wheat and corn responded better to P than to K if compared with sweet potato (**Table 3**). Conversely, sweet potato showed a larger response to K which is not surprising given the large K requirements of tuber crops. Wheat showed a much larger response to P than did corn, which is most likely an effect of the crop season since wheat is grown during the winter season, and as such, is exposed to conditions of lower soil P availability compared to the summer. Given this response, farmers need to be aware of the importance of maintaining adequate soil P fertility in order to support the winter wheat season.

Table 3. Crop yield response to fertilizer treatment.

	Four year yield average, t/ha		
Treatment	Wheat	Corn	S. Potato[1]
$N_0P_0K_0$(CK)	1.6	4.2	3.7
$N_1P_2K_2$	2.9	7.2	4.8
$N_2P_0K_2$ (OPT-P)	2.2	6.5	4.4
$N_2P_1K_2$	2.7	7.2	4.7
$N_2P_2K_2$(OPT)	3.2	7.7	5.1
$N_2P_3K_2$	3.1	7.3	4.7
$N_2P_2K_0$ (OPT-K)	2.8	6.6	4.1
$N_2P_2K_1$	3.0	7.3	4.5
$N_2P_2K_3$	3.2	7.2	4.8
$N_3P_2K_2$	3.0	7.4	4.8

[1]Sweet potato yield is usually converted from its fresh yield to an equivalent grain yield using a 5:1 ratio.

Yearly weather conditions exerted a prominent cause of year-to-year variability in yield for the three individual crops grown within the rotation. However, the schedule of selected treatments does outline a nutrient management strategy able to help minimize these gaps in productivity. Wheat, corn, and sweet potato yields showed annual responses to increased application of N, P, and K fertilizer, but they also showed a tendency to decrease, or level off, under the highest application rates (**Table 4**). The OPT produced the highest combined rotation yield, while zero fertilizer input produced 60% of the OPT. Omission of P or K decreased the average yield potential of the rotation by 17% and 15%, respectively. Total rotation yield varied considerably between years, but tended to decline over time regardless of treatment. Although this trend may imply that some other yield-limiting factor may have been induced by the experiment, this needs further study to confirm.

Table 4. Response of total crop yield (complete rotation) to fertilization, t/ha.

Treatment	2001/02	2003	2004	2005	Average
$N_0P_0K_0$(CK)	10.2**	9.8**	7.7**	10.0**	9.4
$N_1P_2K_2$	17.7	14.9	13.5	14.7	15.2
$N_2P_0K_2$ (OPT-P)	13.9**	14.0**	12.5**	12.3**	13.2
$N_2P_1K_2$	16.3	14.6*	13.6	13.7	14.5
$N_2P_2K_2$(OPT)	17.5	15.8	14.6	15.6	15.9
$N_2P_3K_2$	16.3	14.7*	14.0	15.2	15.0
$N_2P_2K_0$ (OPT-K)	14.1**	14.4**	12.5*	13.1**	13.5
$N_2P_2K_1$	15.6	15.2	13.6	14.5	14.7
$N_2P_2K_3$	17.3	13.8*	14.2	15.3	15.1
$N_3P_2K_2$	16.1	15.6	14.0	13.9	14.9

*, ** Denotes yields significantly different than the OPT at $p = 0.05$ and $p = 0.01$, respectively.

The cause of the decrease in total rotation yield over the course of the study can be isolated to steady yield declines in wheat, and to a greater extent sweet potato, since corn yields kept increasing over time. Taking the OPT treatments as ex-

Observing plots are Mr. Li (right) collaborator at Chongquing Ag-Tech Extension Center, and Ms. Guoling You, Head of the Soil and Fertilizer Station at Liangping County.

amples, the yield decrease from 2002 to 2005 was more severe for sweet potato (-50%) than for wheat (-9%), while corn yields increased from 6.3 t/ha in 2001 to 9.0 t/ha (+43%) in 2005. Thus, gains in corn productivity were received at the expense of declining sweet potato productivity.

Since corn and sweet potato were interplanted, this sharp contrast is most likely a reflection of the two crops' strong competition for sunlight, moisture, and nutrients. Given the importance of corn to the region, farmers will continue to explore their potential for making further gains in corn yields. Sweet potato carries a much lower market price and storage of this crop is more demanding, both in terms of space and ambient environment. Regardless, some balance in this productivity trade-off is required. In such intercropping systems, farmers are advised to manage crop competition through adjustments in plant density and/or planting date so that yields in both crops can be sustained at the desired, albeit compromised levels. BC

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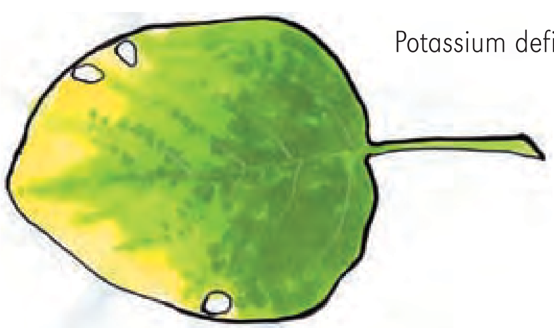
Recognizing Soybean Field Problems

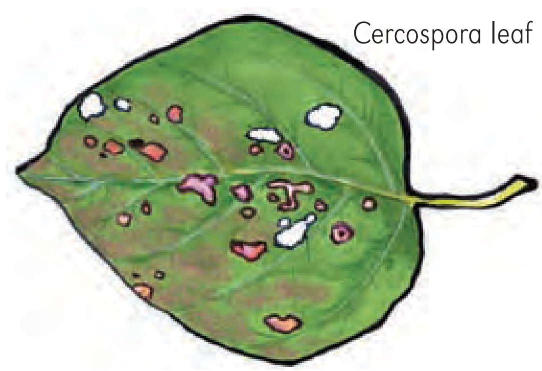
Understanding how various nutrient imbalances, disease risks, and other factors threaten soybean plant health, production, and seed quality can be valuable in diagnosing and preventing field problems.

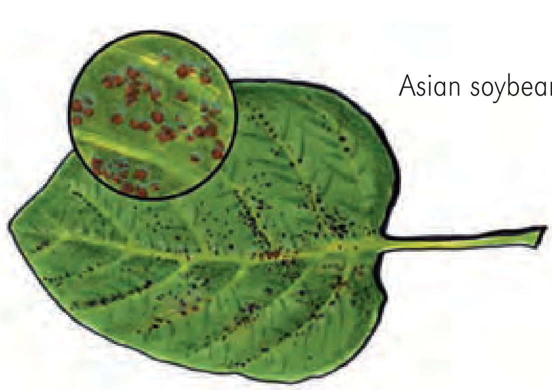
Shown on this page are a few examples illustrating symptoms from the IPNI publication titled *Be Your Own Soybean Doctor*. It is intended to help growers, consultants, and others in becoming more familiar with symptoms of nutrient deficiencies, toxicities, diseases, and other disorders in soybean production. While it does not substitute for diagnostic tools such as plant tissue analysis and soil testing, the guide can be useful in distinguishing and identifying various field problems. It features 40 color illustrations with brief discussion of each.

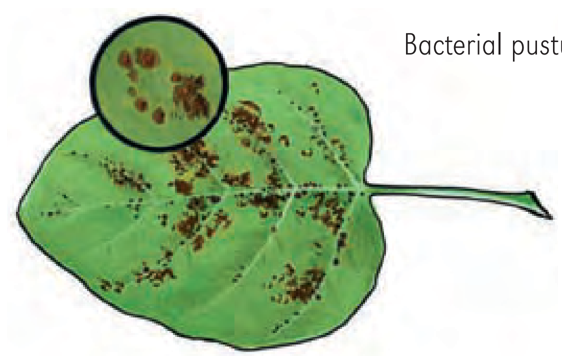
The full color publication is 8 pages, 8 ½ x 11 in., and patterned after the classic *Be Your Own Corn Doctor*, which has been widely used for many years. *Be Your Own Soybean Doctor* is available for 50 cents (US$0.50) per copy, plus shipping/handling. Discounts are available on quantity orders.

Contact: Circulation Department, IPNI, 3500 Parkway Lane, Suite 550, Norcross, GA 30092-2806; phone 770-825-8082 or 825-8084; fax 770-448-0439. BC


Potassium deficiency


Cercospora leaf blight/Frogeye


Asian soybean rust


Bacterial pustule

A Global Framework for Fertilizer BMPs

By T.W. Bruulsema, C. Witt, Fernando García, Shutian Li, T. Nagendra Rao, Fang Chen, and S. Ivanova

This paper describes a framework designed to facilitate development and adoption of best management practices (BMPs) for fertilizer use, and to advance the understanding of how these practices contribute to the goals of sustainable development. The framework guides the application of scientific principles to determine which BMPs can be adapted to local conditions at the practical level.

At the farm level, cropping systems are managed for multiple objectives. Best management practices are those that most closely attain those objectives. Management of fertilizer use falls within a larger agronomic context of cropping system management. A framework is helpful for describing how BMPs for fertilizer use fit in with those for the agronomic system.

The goals of sustainable development, in the general sense, comprise equal emphasis on economic, social, and ecological aspects (Brundtland, 1987). Such development is essential to provide for the needs of current and future generations. At the farm level, however, it is difficult to relate specific crop management practices to these three general aspects. Four management objectives are applicable to the practical farm level of all cropping systems (Witt, 2003). These four objectives are productivity, profitability, cropping system sustainability, and a favorable biophysical and social environment (PPSE). They relate to each other as illustrated in **Figure 1**.

Fertilizer use BMPs comprise an interlinked subset of crop management BMPs. For a fertilizer use practice to be considered "best", it must harmonize with the other agronomic practices in providing an optimum combination of the four objectives, PPSE. It follows that the development, evaluation, and refinement of BMPs at the farm level must consider all four objectives, as must selection of indicators reflecting their combined impact at the regional, national, or global level. Appropriate indicators for use at different scales are further discussed below in the section on performance indicators.

Figure 1. Illustration of a global framework for BMPs for fertilizer use. Fertilizer use BMPs—applying the right nutrient source at the right rate, time, and place—integrate with agronomic BMPs selected to achieve crop management objectives of productivity, profitability, sustainability, and environmental health. A balanced complement of indicators is needed to reflect the influence of fertilizer BMPs on the four crop management objectives at the farm level, and on the economic, ecological, and social goals for sustainable development on the broader scale for regional public policies.

Cropping System Management Objectives

Productivity. For cropping systems, the primary measure of productivity is yield per unit area of cropland per unit of time. Productivity should be considered in terms of all resources, or production factors, involved. Several indicators describing production and input use efficiencies are probably required to properly evaluate productivity.

Profitability. Profitability is determined by the difference between the value of the produce (gross benefit or revenue) and the cost of production. Its primary measure is net benefit per unit of cropland per unit of time. The profitability gain of a specific management practice is the increase in gross revenue it generates, less its marginal cost.

Sustainability. Sustainability—at the level of the cropping system—refers to the influence of time on the resources involved. A sustainable production system is one in which the quality (or efficiency) of the resources used does not diminish over time, so that "outputs do not decrease when inputs are not increased" (Monteith, 1990).

Environment (biophysical and social). Crop production systems have a wide range of effects on surrounding ecosystems through material losses to water and air. Specific effects can be limited to some extent by practices designed to optimize efficiency of resource use. Management choices at the farm level, when aggregated, also influence the social environment through demand for labor, working conditions, changes in ecosystem services, etc.

Fertilizer Management Objectives

Fertilizer use BMPs essentially support the four objectives identified for cropping systems management and can be aptly described as the selection of the right source for application at the right rate, time, and place (Roberts, 2007). Fertilizer source, rate, timing, and placement are interdependent, and are also interlinked with the set of agronomic management practices applied in the cropping system, as illustrated in **Figure 1**.

Scientific Principles

Specific scientific principles apply to crop and fertilizer use BMPs as a group and individually. These principles are

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

both global and applicable at the practical farm management level. The application of these scientific principles may differ widely depending on the specific cropping system under consideration. **Specific principles relevant to each category of BMPs are listed below.**

1) Crop Management
   a) Seek practical measured validation.
   b) Recognize and adapt to risks.
   c) Define performance indicators.
   d) Ensure two-way feedback between global and practical farm levels.
2) Fertilizer Management
   a) Be consistent with understood process mechanisms.
   b) Recognize interactions with other cropping system factors.
   c) Recognize interactions among nutrient source, rate, time, and place.
   d) Avoid detrimental effects on plant roots, leaves and seedlings.
   e) Recognize effects on crop quality as well as yield.
   f) Consider economics.
3) Source
   a) Supply nutrients in plant-available forms.
   b) Suit soil physical and chemical properties.
   c) Recognize synergisms among nutrient elements and sources.
   d) Recognize blend compatibility.
   e) Recognize benefits and sensitivities to associated elements.
   f) Control effects of non-nutritive elements.
4) Rate
   a) Use adequate methods to assess soil nutrient supply.
   b) Assess all indigenous nutrient sources available to the crop.
   c) Assess crop demand for nutrients.
   d) Predict fertilizer use efficiency.
   e) Consider soil resource impacts.
   f) Consider rate-specific economics.
5) Time
   a) Assess timing of crop uptake.
   b) Assess dynamics of soil nutrient supply.
   c) Recognize timing of weather factors influencing nutrient loss.
   d) Evaluate logistics of field operations.
6) Place
   a) Recognize root-soil dynamics.
   b) Manage spatial variability within fields and among farms.
   c) Fit needs of tillage system.
   d) Limit potential off-field transport of nutrients.

The number of scientific principles applicable to a given practical farming situation is considerable. Narrowing down to a set of BMPs appropriate to the practical level requires the involvement of qualified individuals: producers and advisers who understand both the principles and their application. Further details on these principles are provided in IPNI (2008).

Performance Indicators

Performance indicators need to reflect the influence of fertilizer BMPs on all four crop management objectives. Nutrient use efficiency (NUE, yield or nutrient uptake per unit fertilizer nutrient applied) is often considered a foremost indicator relating to fertilizer use. However, as shown in **Figure** 1, it relates much more directly to profitability and productivity than it does to sustainability and environmental health. Other indicators of nutrient use efficiency exist (Dobermann, 2007; Snyder and Bruulsema, 2007) which differ in how well they relate to the four objectives. For example, one of the most important performance indicators for N is agronomic efficiency, the increase in grain yield per unit fertilizer nutrient applied. However, a low agronomic efficiency can be acceptable for nutrients such as P and K, for which a different measure of efficiency – partial nutrient balance – can be more relevant to the avoidance of soil nutrient depletion or excessive buildup.

The partial list of indicators shown in **Figure 1** is described further in **Table 1**. The set of performance indicators that describes the full impact of a combination of fertilizer BMPs varies depending on the scale of consideration. All stakeholders need to contribute to the selection of indicators for optimum attainment of the four management objectives, PPSE. The framework concept we propose is helpful in ensuring that the set of indicators chosen provides a balanced reflection of the four objectives, in harmony with sustainable development goals.

Conclusion

Best management practices for fertilizer use are those that support the achievement of the four main objectives of cropping systems management: productivity, profitability, sustainability, and environmental health. A strong set of scientific principles guiding the development and implementation of fertilizer use BMPs has evolved from a long history of agronomic and soil fertility research. Those principles–when seen as part of the global framework–show that the most appropriate set of fertilizer use BMPs can only be identified at the local level where the full context of each practice is known. The global framework for these BMPs also shows the need for employing a balanced complement of indicators to accurately describe the benefits and risks of fertilizer use in the context of sustainable development. BC

Dr. Bruulsema, Dr. Witt, Dr. García, Dr. Li, Dr. Rao, Dr. Chen, and Dr. Ivanova are IPNI scientific staff located in various regions of the world. All are members of the BMP Working Group of IPNI. Contact: Tom.Bruulsema@ipni.net.

Table 1. Performance indicators for fertilizer BMPs related to crop management objectives.

Management Objective	Performance Indicator	Description
Productivity	Yield	Amount of crop harvested per unit of cropland per unit of time.
	Quality	Amounts of crop components harvested (sugar, protein, minerals, etc.) or other attributes that add value to the harvested product.
	Nutrient Use Efficiency	Yield or nutrient uptake per unit of nutrient applied.
	Water Use Efficiency	Yield per unit of water applied or available. Relevant to irrigated and rainfed production.
	Labor Use Efficiency	Labor demand and supply are critically linked to number and timing of field operations.
	Energy Use Efficiency	Crop yield per unit of energy input.
Profitability	Net Profit	Reflects both volume and value of crop produced, per unit of time, relative to all costs of production. Limitation is inability to deal with externalities that have not been attributed an economic value.
	Return on Investment	Similar to net profit, adding consideration of capital investment and amortization.
Cropping System Sustainability	Adoption	Proportion of producers using particular BMPs. Often easily measured, but context is important.
	Soil Productivity	Reflects changes in soil fertility levels, soil organic matter, and other soil quality indicators.
	Yield Stability	Resilience of crop yields to variations in weather and pests.
	Farm Income	Improvements in livelihood.
	Working conditions	Quality of life issues.
Healthy Social and Biophysical Environment	Water & Air Quality	Concentration and nutrient loading in water bodies of the agricultural watershed or airshed. Limited ability to monitor at farm scale; monitoring at the watershed, regional and global scales is an important public service.
	Ecosystem Services	Difficult to quantify. Important to identify. Can include crop dependence on natural predators and pollinators, link to outdoor recreation, hunting, fishing, etc.
	Biodiversity	Difficult to quantify – can be descriptive.
	Soil Erosion	Degree of soil coverage by actively growing crops and crop residues.
	Nutrient Loss	Specific losses of nutrients to water and air. Since there are many pathways, these can be difficult to measure at the farm level.
	Nutrient Balance	A total account of nutrient inputs and outputs, at the soil surface or farm gate. The requirement for nutrient inputs is often linked to the increasing nutrient removal with harvested products as yields increase.

Acknowledgment

Dr. Paul Fixen contributed the groundwork for the framework concept, and his input through the process of its development is gratefully appreciated.

For more on this topic, visit the IPNI website at: **>www.ipni.net/conceptpapers<**.

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Nutrients and Hypoxia in the Gulf of Mexico — An Update on Progress, 2008

By C.S. Snyder

Based on data presented here and in the U.S. Environmental Protection Agency's Science Advisory Board (EPA SAB) 2008 report, there is reason to believe that declines in discharge of N and P to the Gulf of Mexico are proceeding through voluntary actions by farmers, their advisers, and their suppliers. Driven by global economic pressures, local and personal profitability goals and objectives, and a greater environmental consciousness and stewardship ethic, farmers and practitioners are increasingly implementing fertilizer BMPs. These accomplishments are noteworthy and herald progress toward improved fertilizer nutrient use efficiency, which may lead to reductions in N and P loss from farm fields and agricultural watersheds.

Since 1985, the areal extent of hypoxia (≤2 mg/L of dissolved oxygen) in the shallow coastal waters (< 30 m or 100 ft.) of the northern Gulf of Mexico has been estimated annually in late July by scientists with the Louisiana Universities Marine Consortium (LUMCON). **Figure 1** shows the extent of hypoxia beginning in 1985 and through 2007. Historic evidence suggests hypoxia is a natural event, but current science indicates hypoxia in the Gulf has occurred more frequently and extensively in the last half century. These contemporary changes in the size and duration of the hypoxic zone are thought to be most related to nutrient discharges, specifically N and P discharges from the Mississippi and Atchafalaya River Basin (MARB).

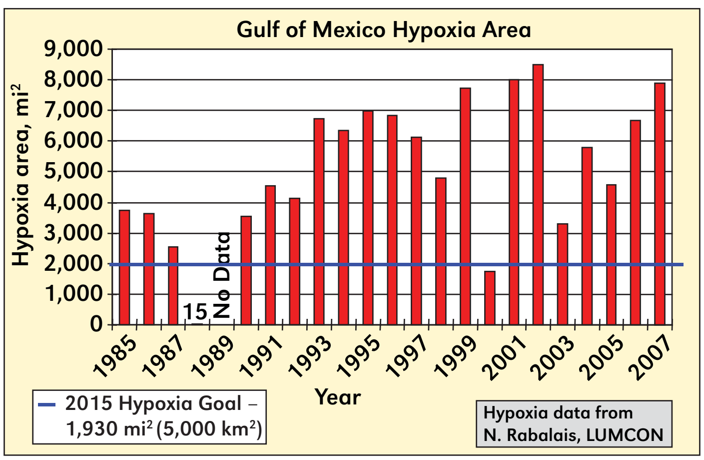
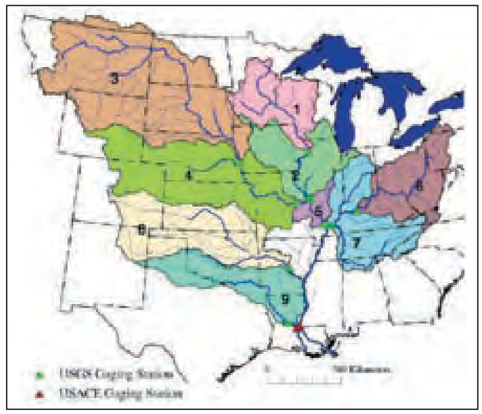


Figure 1. Areal extent of hypoxia in the northern Gulf of Mexico, as determined by annual cruises conducted in late July. Data source: N. Rabalais, LUMCON.

Federal, state, and tribal authorities developed an Action Plan and defined within-Basin goals and the goal of reducing the hypoxic zone in the Gulf of Mexico to a 5-year running average of 5,000 km² (1,930 mi²) by 2015 (MR/GMWNTF, 2001). Since 2001, knowledge has expanded on the complexity of factors (e.g. climate, weather, basin morphology, coastal water circulation patterns, water retention times, freshwater inflows, stratification of freshwater over saltwater, mixing, nutrient loadings, and loss of processing marsh lands along the Louisiana coast) that contribute to the development of hypoxia in the Gulf. For example, a recent report by Hetland and DiMarco (2008) has exposed some of the complexities associated with coastal physical processes, and factors that



Location of nine large sub-basins comprising the MARB that are used for estimating nutrient fluxes (from Aulenbach et al., 2007).

interact with the biology of the ecosystem, which affect hypoxia development and persistence east and west of the shelf region south of Terrebone Bay in Louisiana. These two authors suggest that a water stratification envelope may be the dominant factor affecting the areal extent of hypoxia along the Louisiana-Texas shelf, as opposed to nutrients delivered by the Mississippi and Atchafalaya discharges.

At the request of the Mississippi River/Gulf of Mexico Watershed Nutrient Task Force (MR/GMWNTF), EPA impaneled a team of leading scientists to form a hypoxia Science Advisory Board to reassess nutrient load reductions achieved, the responses of the hypoxic zone and associated water quality and habitat conditions, and economic and social effects since the 2001 Action Plan (MR/GMWNTF, 2001) was released. The SAB reported: *"Hypoxia can occur naturally in deep basins, fjords, and oxygen minimal coastal zones associated with upwelling. However, nutrient-induced hypoxia in shallow coastal and estuarine systems is increasing worldwide"* (EPA SAB, 2008). The SAB report also stated that *"recent science has affirmed the basic conclusion that contemporary changes in the hypoxic area in the northern Gulf of Mexico are primarily related to nutrient fluxes from the MARB."* A new Action Plan is in development and a draft has been released to the public (MR/GMWNTF, 2008).

Former N discharge reduction goals (MR/GMWNTF, 2001) were aimed principally at NO_3-N discharge reduction (actually, reported as the combined measure of NO_3^- and NO_2^- forms of N), but the 2008 EPA SAB report recommended reductions in

Abbreviations and notes for this article: N = nitrogen; P = phosphorus; BMPs = best management practices; NO_3^- = nitrate; NO_2^- = nitrite; NH_4^+ = ammonium; UAN = urea ammonium nitrate; NO_y = reactive N oxides plus the compounds produced from their oxidation.

total N discharge: the combination of organic and inorganic N (NH_4^+ and NO_3^-). In addition, significant reductions in total P discharge were also recommended. In contrast to prior thinking and conventional wisdom, research has shown that P discharge plays a role in the initiation of phytoplankton (i.e. algae) blooms in the shallow, lower salinity waters nearer the Gulf shore.

To reduce the size of the hypoxic zone and improve water quality in the MARB, the EPA SAB (2008) panel recommended a dual nutrient strategy:

- reduce total N discharge at least 45% (to approximately 870,000 metric tons/yr or 960,000 tons/yr), and
- reduce total P discharge at least 45% (to approximately 75,000 metric tons/yr or 83,000 tons/yr).

Results of some predictive modeling studies have led some authors to suggest that increased precipitation amounts and intensities associated with climate change may create conditions that would require even larger nutrient discharge reductions (e.g. 50 to 60%) to shrink the size of the hypoxic zone (Donner and Scavia, 2007; Justic et al., 2007).

The Atchafalaya River discharge, because of the Mississippi River diversion (mandated by legislation since the mid-1970s at 30% of the combined flow of the Mississippi River and the Atchafalaya River) is contributing about 50% of the freshwater to the Louisiana-Texas shelf, while the remaining 50% of the freshwater is discharged via the main Mississippi River plume southeast of New Orleans. These massive inputs of freshwater, coupled with weak tidal energies, seasonally variable stratification strength, high water temperature, and wind effects from fronts and storms result in complex coastal circulation and stratification physics, which exert an important influence on the seasonal development and persistence of hypoxia.

Trends in Water, N, and P Discharge

The following trends in N and P discharge were identified in the EPA SAB (2008) report:

- Comparisons of 2001 to 2005 (most recent 5-year data) with the reference period of 1980 to 1996 showed the following. Also see **Table 1**.
  - annual average water flow (flux) to the Gulf decreased about 6%, while spring flow (April-June) decreased 11%,
  - annual NO_3-N discharge decreased 15%, while spring NO_3-N discharge decreased 12%,
  - annual total Kjeldahl N (organic + NH_4-N) discharge decreased 30%, while spring discharge decreased 32%,
  - annual total N discharge decreased 21%, while spring total N discharge decreased 19%, and
  - annual total P discharge increased 12%, while spring total P discharge increased 10%.
- Clearly, these annual and spring N and P discharge changes are not directly proportional to changes in the freshwater volume delivered to the Gulf. Nutrient management, cropping patterns, and areas within the MARB where leaching, runoff, and drainage occur, and coastal ocean physics are also important factors that must be considered in plans to reduce nutrient loss to the Gulf.
- It is important to note that the 21% decline in total N discharge from the MARB to the Gulf of Mexico in 2001 to 2005 is an achievement of two-thirds of the 30% reduction objective recommended in the 2001 Action Plan to help meet the 5-year running average 5,000 km^2 (1,930 mi^2) hypoxic area goal. However, this sizeable reduction in total N discharge does not appear to have affected the annual size of the hypoxic zone (see **Figure 1**). The size of the zone in 2007 was the third largest recorded since 1985.
- Contributions of the major MARB sub-basins to water flow, and to total N and total P discharge delivery to the Gulf of Mexico, are shown in **Table 2.** These same nutrient contributions are shown in **Table 3** on a land area basis. The Upper Mississippi Sub-basin and the Ohio-Tennessee Sub-basin combined account for the majority of the freshwater flow and N and P delivery to the Gulf, while the other sub-basins also contribute significantly. On a per hectare land area basis, the Lower Mississippi Sub-basin contributes total P in a magnitude similar to the Upper Mississippi and the Ohio-Tennessee Sub-basins (**Table 3**).
- Total freshwater discharge to the Gulf varies considerably among years **(Figure 2)**, has increased since 1955, since the 1970s, and…as noted above…since the 1980 to 1996 period (**Table 1**).
- Since the mid-1980s, annual NO_3-N, NH_4-N, particulate/organic-N, and total N discharge (flux) from the MARB **(Figure 3)** have declined, especially the total N delivered to the Gulf.
- Total P discharge has remained constant or increased slightly since the 1980s, while orthophosphate P and silicate discharges have declined slightly **(Figure 4).**
- Spring (April-June) discharge (flux) of freshwater, NO_3-N, Kjeldahl N, and total N from the MARB have all declined since the early 1980s (**Figure 5**).
- Spring (April-June) discharge (flux) of soluble reactive P (orthophosphate), total P and silicate from the MARB have also declined since the early 1980s (**Figure 6**).

Table 1. Average annual and spring (April-June) combined water flow, NO_3-N, total Kjeldahl N (organic N + NH_4-N), and total N discharge from the combined Mississippi and Atchafalaya Rivers to the Gulf of Mexico for 2001 to 2005 compared against the reference period 1980-1996. Source: EPA SAB, 2008.

	1980-1996	2001-2005	Change
	million m^3 (water) or million metric tons		%
Annual			
Water	692,500	652,500	-6
NO_3-N	0.96	0.81	-15
Total Kjeldahl N	0.61	0.43	-30
Total N	1.58	1.24	-21
Spring			
Water	236,800	210,600	-11
NO_3-N	0.38	0.33	-12
Total Kjeldahl N	0.21	0.14	-32
Total N	0.59	0.48	-19

Table 2. Average nutrient discharge for the five large sub-basins in the Mississippi–Atchafalaya River Basin for the 2001-2005 water years (EPA SAB, 2008). Values in parentheses indicate % of total Basin discharge.

Sub-basin	Land Area		Water flow	NO_3-N	NH_4-N and organic N (Total Kjeldahl N)	Total P
	km²	mi²	million m³/yr	- - - - - - - -	1,000 metric tons/yr	- - - - - - - -
Upper Mississippi[1]	493,900	190,600	116,200 (18)	349 (43)	136 (32)	40 (26)
Ohio-Tennessee	525,800	203,000	279,800 (43)	335 (41)	175 (41)	59 (38)
Missouri	1,353,300	522,400	60,080 (9)	79 (10)	84 (20)	30 (20)
Arkansas-Red	584,100	225,500	67,200 (10)	29 (4)	44 (10)	9 (6)
Lower Mississippi[1]	183,200	70,700	129,550 (20)	22 (3)	-8 (-2)	16 (10)

[1] Nutrient discharge calculated by differences. Negative values occur downstream where a downstream site had a lower discharge than the upstream site, that result in errors in discharge estimates or a real net loss of nutrients.

The MARB is one of the largest river systems in the world.

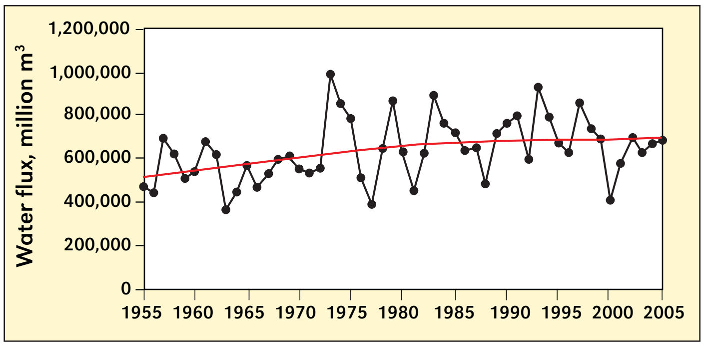


Figure 2. Annual water discharge (flux) for the combined Mississippi and Actchafalaya Rivers to the Gulf of Mexico, 1955-2005 (from EPA SAB, 2008). Red curve represents statistically-based, smoothed trend.
Source: EPA SAB, 2008.

Table 3. Average annual nutrient yields for the five large sub-basins in the Mississippi-Atchafalaya River Basin for water years 2001-2005. Source: EPA SAB, 2008.

Sub-basin	NO_3-N	NH_4-N and organic N (Total Kjeldahl N)	Total P
	- - - - - - - -	kg/ha/yr	- - - - - - - -
Upper Mississippi	7.1	2.7	0.8
Ohio-Tennessee	6.4	3.3	1.1
Missouri	0.6	0.6	0.2
Arkansas-Red	0.5	0.8	0.1
Lower Mississippi	1.2	-0.5	0.9

- From 2001 to 2005, based on data from the U.S. Geological Survey (USGS), the upper Mississippi and Ohio-Tennessee River sub-basins contributed about 82% of NO_3-N, 69% of the total Kjeldahl N (organic N plus NH_4-N), and 58% of total P discharged annually to the Gulf of Mexico, while these sub-basins represent only about 31% of the entire MARB drainage area.
- From 2001 to 2005, point sources (in contrast with diffuse nonpoint sources) represented 22% of the annual average total N and 34% of the annual average total P discharged to the Gulf.

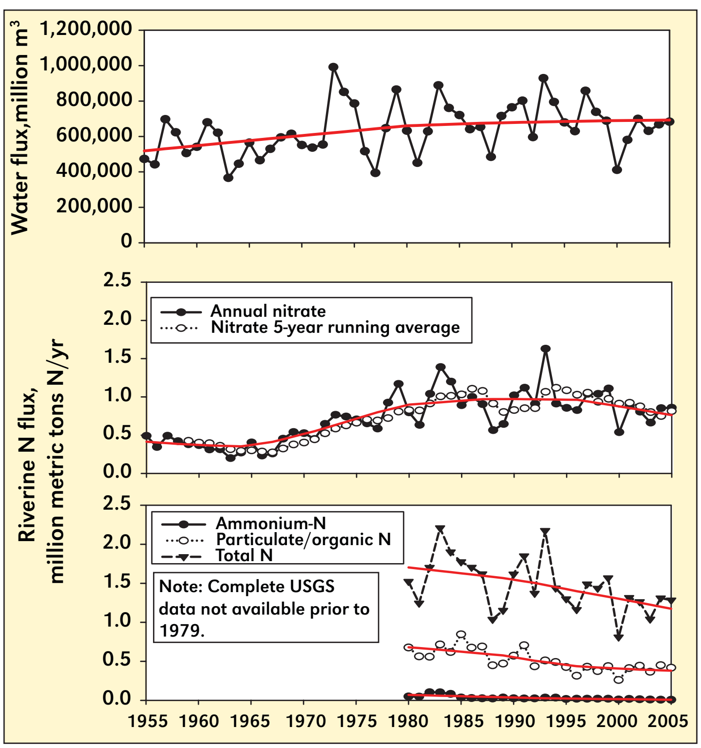


Figure 3. Annual N discharge (flux) for the Mississippi-Atchafalaya River Basin for 1955-2005. Red curves represent statistically-based, smoothed trends.
Source: EPA SAB, 2008.

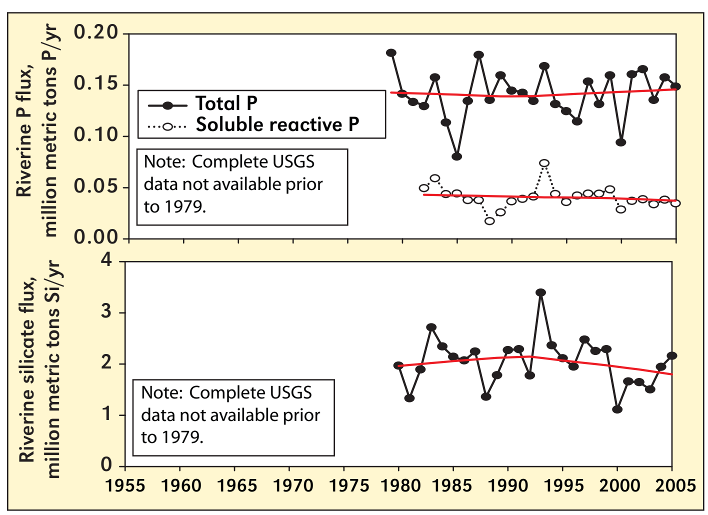


Figure 4. Annual P and silicate discharge (flux) for the Mississippi-Atchafalaya River Basin for 1979-2005. Red curves represent statistically-based, smoothed trends.
Source: EPA SAB, 2008).

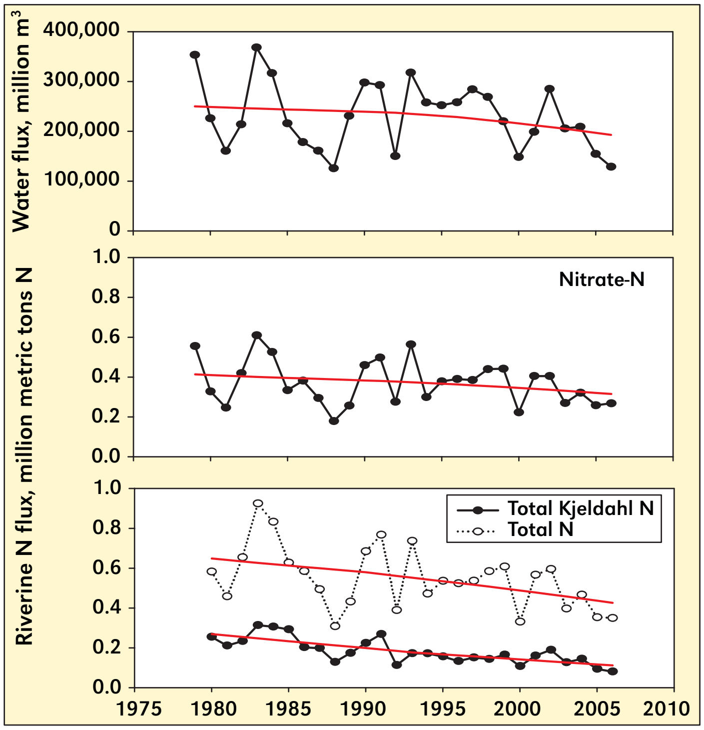


Figure 5. Spring (April-June) water flow, NO_3-N, Kjeldahl N, and total N discharge (flux) for the Mississippi-Atchafalaya River Basin for 1979-2006. Red curves represent statistically-based, smoothed trends. Source: EPA SAB, 2008.

Correlations between N and P Discharge and Hypoxia

- Correlations of the discharges of total N, NO_3-N, total P, and orthophosphate-P with the annual size of the hypoxic zone for 1985 through 2006 (**Table 4**) show the following.
  - o Relationships of annual hypoxia with annual total N discharge are weaker than relationships with annual total P discharge. The portion of the total variation in the annual size of Gulf hypoxia explained by annual total N discharge was less than 2% (R^2 =0.019), while annual total P discharge explained 4% (R^2 =0.04), of the variation in the annual size of hypoxia.
  - o Relationships of hypoxia with annual discharge of NO_3-N and annual discharge of orthophosphate-P are slightly stronger compared to annual total N and total P discharges. However, the correlations are still weak ($R^2 < 0.25$).

Table 4. Portion of the variability in the size of the annual hypoxic area in the northern Gulf of Mexico explained by the discharge of N and P annually and in the spring (April-June), 1985-2006.

Nutrient	Annual Discharge	Spring Discharge
	R^2*	
Total N	0.019	0.148
Total P	0.040	0.187
Nitrate-N	0.128	0.293
Orthophosphate-P	0.205	0.395

*Based on simple linear regression.

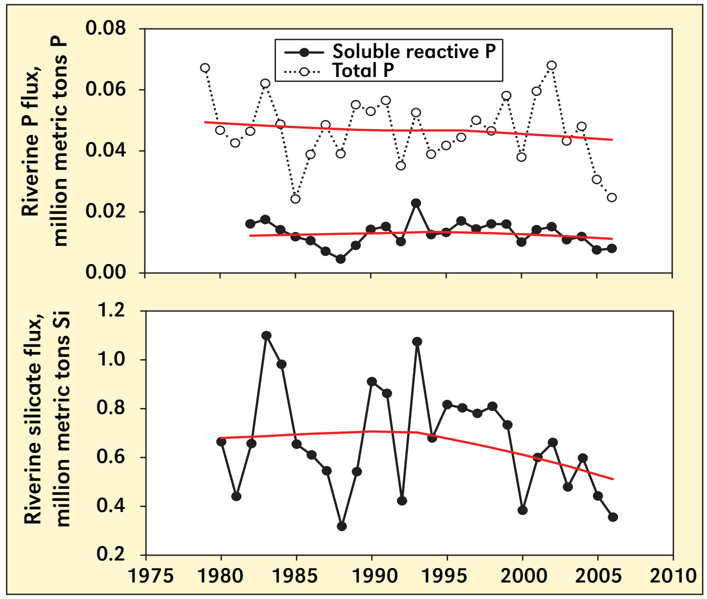


Figure 6. Spring (April-June) P and silicate discharge (flux) for the Mississippi-Atchafalaya River Basin for 1979-2006. Red curves represent statistically-based, smoothed trends. Source: EPA SAB, 2008.

  - o Relationships of hypoxia with spring discharges of total N, total P, NO_3-N, and orthophosphate-P are stronger compared to annual discharges.
    - Spring discharges of these nutrients explain more of the annual variation in the size of the hypoxic zone than do the annual total discharges of these nutrients.
    - The soluble forms of N (NO_3^-) and P (orthophosphate) discharged in the spring show a relationship with annual hypoxia at least twice as strong as relationships with the total quantities of N and P discharged in spring.
    - These spring-discharge relationships clearly point to opportunities for skilled nutrient management and implementation of improved fertilizer BMPs to help retain more N and P within farm fields, and to improve crop N and P use efficiencies (Snyder and Bruulsema (2007).
    - These N and P spring-discharge relationships with annual hypoxic area also lend support to arguments that other factors besides N and P discharge (e.g. stratification, specific circulation patterns, "ecosystem memory", etc.) may have equal or more dominant effects on hypoxia development and persistence. For example, Turner et al. (2006) reported on the influence of seasonal nutrient discharge and hypoxia in the northern Gulf of Mexico for 1985 through 2004. They indicated that because of "ecosystem memory" or residual effects, some passage of time may be required before effects on dissolved oxygen concentrations are experienced…even after significant reductions in nutrient discharge to coastal waters have occurred.

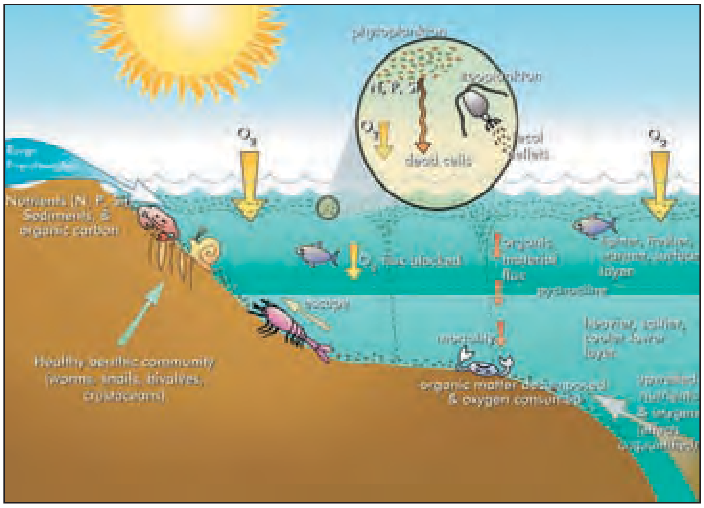


Illustration from EPA

This schematic describes some of the processes contributing to hypoxia development.

Trends in Nutrient Mass Balances

- Recoverable manure (from confined animal feeding operations) represents less than about 6% of the total N (fertilizer, legume, recoverable manure) inputs in North America (Fixen and Johnston, 2002) and within the MARB. From 1990 to 1996, the USDA-estimated crop acreage receiving manure was as follows: corn, 17%; soybean, 6%; winter wheat, 3%; and cotton, 4% (Ludwick and Johnston, 2002). Although recoverable manure may be an important N and P source locally, it should probably not be considered a major nutrient input source within the entire MARB.
- Nutrient mass balances were estimated for the MARB in the EPA SAB (2008) report:
  - o Analyses of the available data indicated that net anthropogenic N inputs have declined in the past decade (**Figure 7**) because of increased crop yields (resulting in increased N removal in crop harvest), reduced or redistributed livestock populations, and small changes in N fertilizer N inputs.
    - About 22% of the total N and 34% of the total P discharged to the Gulf yearly are attributed to point sources. The remainder of total N and total P inputs in the MARB are estimated to come from non-point sources. The report stated: "Components of the N mass balance such as denitrification, biological N_2 fixation, manure N, and soil N pool processes such as mineralization and immobilization are not measured each year. Only biological N_2 fixation and manure N can even be estimated, with the other fluxes having little data available to make calculations. Point sources export N and P directly to rivers, yet their contributions continue to be estimated from permits." So, the values shown in **Figures 7 and 8** should be viewed guardedly, with some understanding about these estimate uncertainties.
    - From 1999-2005, net anthropogenic N input estimates and calculations indicated that 54% of non-point source net N inputs in the MARB

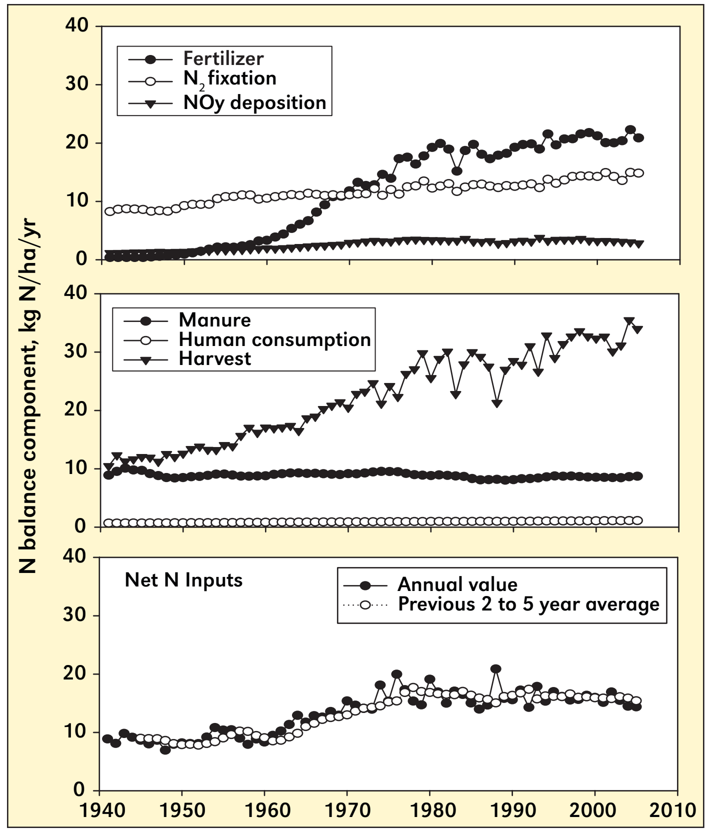


Figure 7. Nitrogen mass balance and net inputs for the Mississippi-Atchafalaya River Basin through 2005.
Source: EPA SAB, 2008.

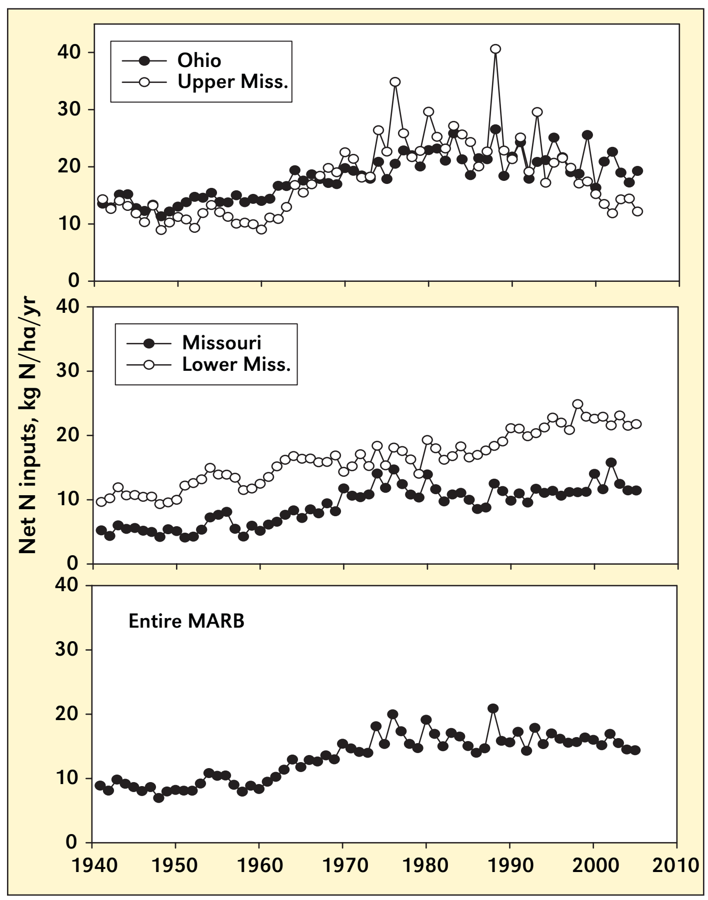


Figure 8. Nitrogen mass balance and net inputs for major regions of the Mississippi-Atchafalaya River Basin through 2005.
Source: EPA SAB, 2008.

were from fertilizer, 37% from biological N fixation, and 9% from atmospheric deposition.

- "Increased crop yield trends, improved plant genetic selection, and pest control may also be contributing to the reduced NO_3-N transported to the northern Gulf of Mexico (NGOM) since the mid-1990s, and the steady decline in total N delivered to the NGOM since the 1980s. Any reductions in N application rates could threaten attainment of high crop yields, which are vital to profitable production, and which have contributed in some measure to the reductions in net N inputs and riverine N discharge" (EPA SAB, 2008).
- Mass balances of N in the upper Mississippi River sub-basin (**Figure 8**) indicate that under the tile-drained corn and soybean management system currently in place, depletion of soil organic N pools may be occurring.
- Net anthropic P inputs for the MARB have decreased in the past decade (**Figure 9**) in association with reduced P fertilizer applications and increased crop yields (resulting in increased P removal in crop harvests).
- Increased crop yields and harvest nutrient removal in the Upper Mississippi and the Ohio River sub-basins have caused the greatest impact on declines in estimated net anthropogenic N inputs and net anthropic P inputs for the entire MARB (**Figures 8 and 9**).

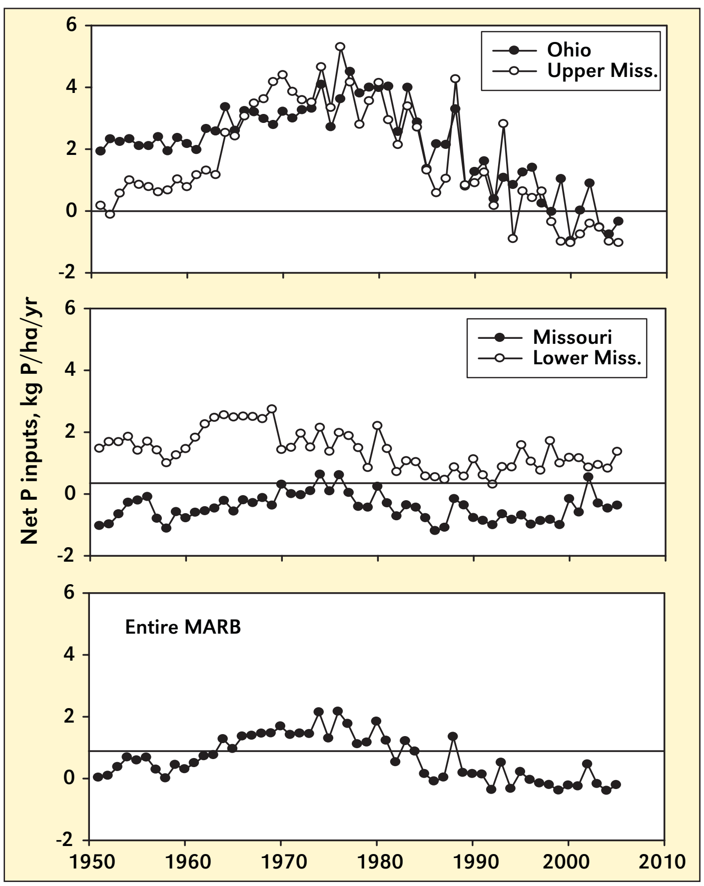


Figure 9. Phosphorus mass balance and net inputs for major regions of the Mississippi-Atchafalaya River Basin through 2005. Source: EPA SAB, 2008.

Fertilizer N Consumption and Shifts Among Sources

In the entire MARB, fertilizer N consumption has been relatively flat or increased slightly in the last two decades (**Figure 7**). In the Midwest, where the bulk of the fertilizer N and P are consumed, and where much of the USA corn crop is produced, there have been shifts in the N tonnages among anhydrous ammonia, UAN, and urea. For example, the combined N consumption of urea and UAN solution has increased and recently surpassed anhydrous ammonia N consumption in six leading corn-producing states (IA, IL, IN, MN, NE, and OH) (**Figure 10**). These shifts among N sources may indicate some change toward spring application timing away from fall applications of anhydrous ammonia, some preference in use of sources toward those presenting lower human health (e.g. direct contact) risks; or the changes may represent shifts in the supply infrastructure, which may translate into local changes in availability of some N sources to farmers.

Corn is the principal N consumer of the crops planted in the MARB. Corn yields have increased since 1990 from 126 bu/A (7.94 t/ha) to 160 bu/A (10.08 t/ha) in 2006 (**Figure 11**). As discussed above, higher crop yields have resulted in increased N removal in harvested grain, with only small increases in N fertilization (**Figures 7 and 10**). The net effect is lower net

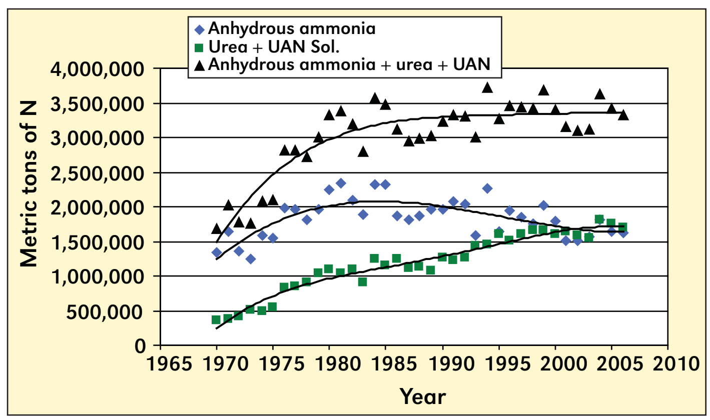


Figure 10. Changes in the consumption of principal fertilizer N sources used in the six leading corn producing states (IA, IL, IN, MN, NE, and OH) for years ending June 30. Sources: AAPFCO, personal communication with H. Vroomen of The Fertilizer Institute; EPA SAB, 2008.

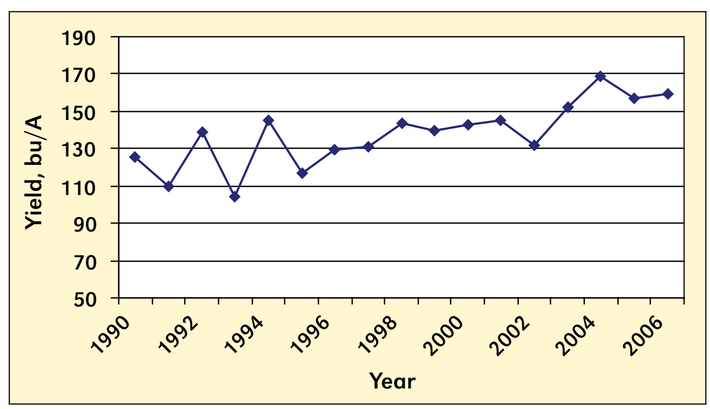


Figure 11. Average corn yields in six leading corn-producing states (IA, IL, IN, MN, NE, and OH), 1990-2006. Source: USDA National Agricultural Statistics Service.

N input to the lands within the MARB (**Figure 8**).

Conclusions

Based on data presented here and in the EPA SAB (2008) report, there is reason to believe that declines in discharge of N and P to the Gulf of Mexico are proceeding through voluntary actions by farmers, their advisers, and their suppliers. Driven by global economic pressures, local and personal profitability goals and objectives, a greater environmental consciousness and stewardship ethic, farmers and practitioners are increasingly implementing fertilizer BMPs. These accomplishments are noteworthy and herald progress toward improved fertilizer nutrient use efficiency, which may lead to further reductions in N and P loss from farm fields and agricultural watersheds.

Increased crop yields, improved plant genetic selection, and improved pest control may all be contributing to the lowered net anthropic N and net anthropic P inputs observed in the last decade or more. These environmental benefits are reflected in lower N and P delivery to the Gulf of Mexico during the peak spring (April-June) discharge. Any actions that could result in reductions in appropriate fertilizer N application rates could threaten attainment of high crop yields. Efficient attainment of high crop yields, which are vital to profitable production and essential to meet the food, fiber, and fuel demands of a growing world population, are contributing to reductions in net N inputs and net P inputs and reductions in delivery of N and P to the Gulf of Mexico.

Farmers will need to maintain their vigilance and improve their skills to achieve further gains in nutrient use efficiency. The fertilizer industry, crop advisers, agricultural consultants, natural resource professionals…public and private partners…are dedicated to reducing and minimizing the environmental footprints associated with commercial fertilizer use. Progress is being made, more is expected, and there is good reason for optimism as knowledge expands, behaviors change, and new technologies become available. We sincerely hope that through these efforts, water quality can be improved throughout the MARB and within the northern Gulf of Mexico. BC

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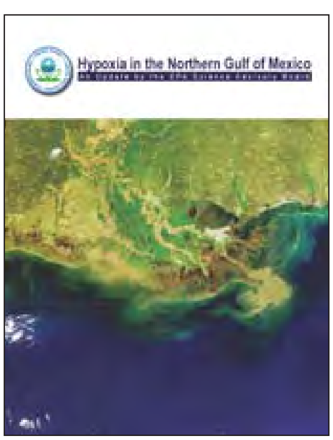

This image shows the cover of the 2008 Hypoxia SAB Report.

Increased crop yields, improved plant genetics, and improved pest control may be reflected in lower N and P discharge to streams and rivers.

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Phosphorus Management for Irrigated Potato Production in Manitoba

By Ramona Mohr and Dale Tomasiewicz

Results of a set of field experiments evaluating potato response to recommended rates of P fertilizer demonstrated yield benefits in 2 of 4 years, and consistent increases in post-harvest Olsen P levels. Findings suggest that petiole critical nutrient concentrations developed in other potato-growing areas may require regional adaption for Manitoba.

Manitoba has become a major contributor to potato production in Canada, with output of over 12 million cwt of processing potatoes valued at $97.3 million in 2001. While P is routinely applied to most potato fields in Manitoba, much of the research regarding potato responses to P in Manitoba was conducted in the 1960s. More recently, Geisel (1995) and Tomasiewicz (1994) conducted field trials to assess P response in irrigated potato. In five field trials conducted from 1991 through 1994, Geisel (1995) reported significant yield increases with P application in two of five trials, with yield increases evident only where soil test P levels were less than 40 lb/A. In a one-year study, Tomasiewicz (1994) found no effect of P application on potato yield or quality for a site that, based on the soil P level, would have been expected to respond to P fertilization most of the time. The objective of this study is to determine the effect of recommended rates of P fertilizer on tuber yield and quality, petiole P concentration, and post-harvest Olsen P levels for irrigated processing potato.

Four field experiments were conducted in Manitoba from 2003 through 2006 to assess the impact of P fertilizer rate on irrigated Russet Burbank potato. Field experiments were conducted on Orthic Black Chernozem soils near Carberry in 2003, 2004, and 2005 (pH 5.6 to 6.2) and near Douglas in 2006 (pH 6.8). Sodium bicarbonate extractable P (Olsen P) levels for the 6 in. depth were 43, 24, 34 and 19 lb/A in 2003, 2004, 2005, and 2006, respectively. A randomized complete block design consisting of four replicates of four P fertilizer rates (0, 30, 60, and 90 lb P_2O_5/A as MAP) was established. Individual plots were typically 52 ft. long, and ranged from 6 to 9 rows wide. Row spacing was 37 in. and within row spacing was typically 15 in. Blanket applications of N, K, and S-containing fertilizers were made as required to ensure nutrients were non-limiting at all sites. Nitrogen applications were adjusted for each P rate to account for N applied in the MAP in order to ensure that all treatments received equal rates of fertilizer N. All pre-plant fertilizer was surface broadcast,

Timing of plant counts, mid-June 2005.

Southern Manitoba P and potato research site, August 2005.

and then thoroughly incorporated. In select years, additional N was top dressed and incorporated at hilling. Potato (cv. Russet Burbank) was planted between late April and late May depending upon the year. Approximately 36 to 39 ft. of the center two rows of each plot were harvested the third week of September each year. Pests were effectively managed and irrigation water applied as required.

In the spring prior to plot establishment, soil samples were collected and the Olsen P concentration determined. Petiole samples were collected at approximately 10 day intervals throughout the growing season. Shortly before tuber harvest, whole plant samples were collected and separated into vines, recoverable roots plus stolons, and tubers. In 2005 and 2006, whole plant samples were collected in all treatments; in 2004, only the 0 and 90 lb P_2O_5/A treatments were sampled.

Growing season conditions varied among years. Cool conditions prevailed throughout the 2004 growing season and, in 2005, precipitation levels were above-normal in the early part of the growing season. Total tuber yield varied among years, averaging 380, 306, 463, and 422 cwt/A in 2003, 2004, 2005, and 2006, respectively. The comparatively lower yields obtained in 2004 were due in part to cooler growing season conditions, including frost in August.

Phosphorus fertilization appeared to have limited effects on tuber yield and quality although the experimental sites selected would have received a recommendation for P fertilizer based on the "Manitoba Soil Fertility Guide" (Manitoba Agriculture, Food and Rural Initiative, 2007). Total tuber yield increased linearly ($p = 0.02$) with increasing P fertilizer rate only in 2005 (**Table 1**). Phosphorus rate had no effect on total tuber yield in 2003 and 2006. In 2004, P rate tended ($p = 0.07$) to influence total tuber yield. Closer examination of the data

Abbreviations and notes for this article: N= nitrogen; P = phosphorus; cwt = 100 wt or 100 lb; MAP = monoammonium phosphate; K = potassium; S = sulfur; $NaHCO_3$ = sodium bicarbonate; ppm = parts per million.

Table 1. Effect of rate of P fertilizer application on yield and tuber size fraction of irrigated Russet Burbank potato for 4 years in Manitoba.

Year	P_2O_5 rate, lb/A	Total yield	< 3 oz	3-6 oz	6-10 oz	10-12 oz	> 12 oz	Marketable
		cwt/A						
2003	0	378.6	22.9	97.6	144.6	37.9	75.6	355.7
	30	390.1	22.1	114.0	130.4	42.9	80.7	368.0
	60	374.1	20.0	85.2	146.1	42.5	80.3	354.1
	90	379.1	22.2	104.3	146.2	56.6	49.6	356.8
	Pr>f	NS	NS	NS	NS	NS	NS	NS
2004	0	312.0	23.5	89.0	106.5	29.7	63.3	288.5
	30	283.5	33.0	93.5	93.9	31.1	32.0	250.5
	60	311.8	28.6	101.2	112.3	32.1	37.7	283.2
	90	316.3	26.1	85.5	112.5	37.3	54.9	290.2
	Pr>f	0.070	0.100	NS	NS	NS	NS	0.029
2005	0	441.8	29.0	119.2	177.2	55.0	61.3	412.6
	30	459.8	35.8	129.8	163.7	49.6	87.4	430.4
	60	466.3	31.5	117.2	177.7	59.0	81.1	435.0
	90	483.0	34.4	113.9	145.0	70.0	119.6	448.5
	Pr>f	0.100	NS	NS	0.080	NS	0.006	NS
2006	0	421.0	36.0	124.8	128.2	50.0	82.2	385.1
	30	423.5	23.9	118.4	160.9	43.7	76.4	399.4
	60	441.5	23.9	108.3	155.3	49.9	104.0	417.6
	90	403.3	35.6	95.9	150.2	49.7	71.9	367.7
	Pr>f	NS	0.009	NS	NS	NS	NS	0.060

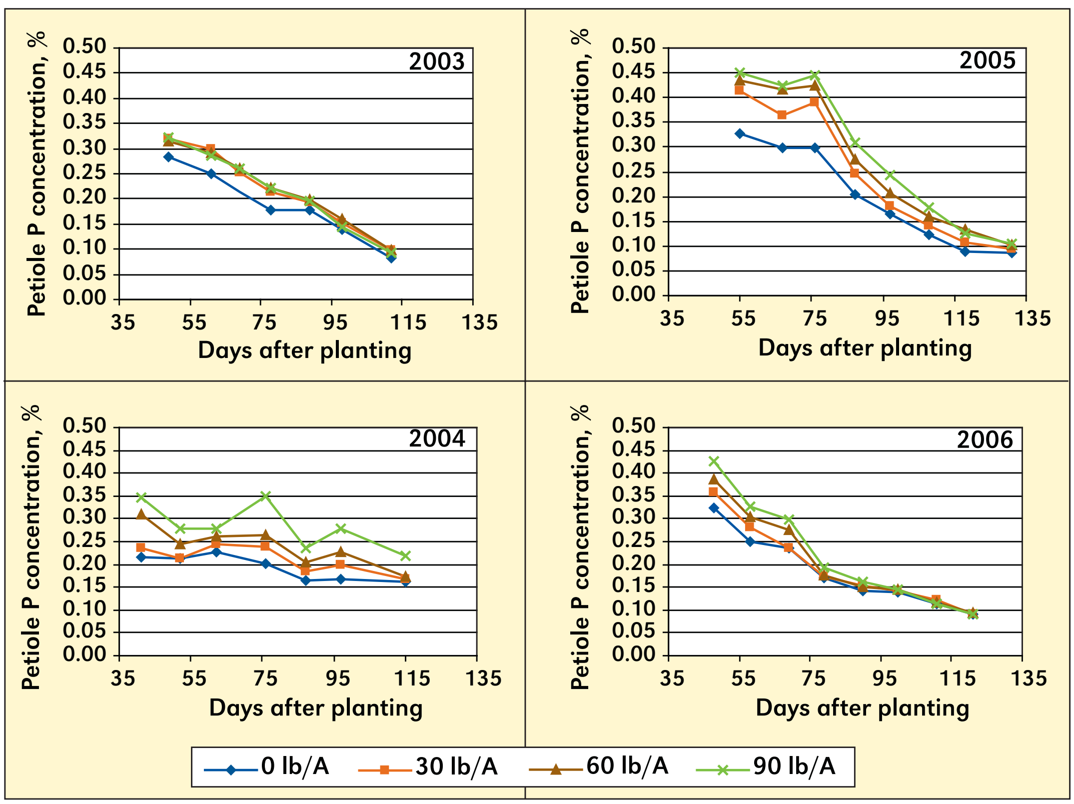

Figure 1. Effect of rate of P fertilizer (lb P_2O_5/A applied as broadcast MAP) on total P concentration in petioles of irrigated Russet Burbank potato in Manitoba (2003-2006).

revealed that the treatment receiving 30 lb P_2O_5/A had a numerically lower yield than any other treatment, although the reason for this effect is unclear. In 2005 and 2006, increasing P rate increased marketable yield (**Table 1**). A significant linear effect was evident in 2005 (p = 0.03), and a significant quadratic effect was evident in 2006 (p = 0.02). In part, a somewhat higher soil test P level in 2003—and poor growing season conditions that restricted crop growth in 2004—may have limited crop responses to fertilizer application in those years.

The rate of P fertilizer applied had limited effects on tuber quality (data not shown). Specific gravity was not affected by P rate except in 2004 when increasing P rate resulted in a statistically significant linear increase in specific gravity. In 2003, P rate tended to influence specific gravity, but increasing P rate had inconsistent effects. The occurrence of defects such as rot and greening was generally very low throughout the course of the study, while the occurrence of hollow heart/brown center averaged 15.2%, 15.1%, 9.5%, and 2.1% of the tubers assessed (on a weight basis) in each of 2003, 2004, 2005, and 2006, respectively. Preliminary analysis suggests that P rate had limited effects on hollow heart.

Petiole P concentration generally declined over the course of the growing season (**Figure 1**). In 2004 and 2005, increasing P rate increased petiole P concentration for each sampling date. In 2006, increasing P rate also increased petiole P concentration in the early part of the growing season, but this effect was not evident for later sampling dates. In 2003, P fertilization similarly increased or tended to increase petiole P concentration at most sampling dates, but effects were not as pronounced as in 2004 and 2005. In an extension bulletin from the University of Idaho, petiole P concentrations of <0.17% were considered low, 0.17 to 0.22% marginal, and >0.22% sufficient for the fourth petiole of Russet Burbank potatoes during tuber bulking (Stark et al., 2004). In the current study, petiole P concentration in most treatments at most sites fell below 0.22% as the season progressed. However, increasing P rate increased marketable yield only in 2005 and 2006.

Woods et al. (2002) reported that the adequate range for petiole P based on standards used in the northwest U.S. ranged from 0.22 to 0.62% in early July, from 0.20 to 0.50% in late July, and from 0.16 to 0.40% in mid-August. Using these criteria, the petiole P concentration in all treatments in all site-years fell within the adequate range in early July. Petiole P concentration also fell within the adequate range in late July in all years except 2006 where petiole P concentration fell below 0.20% by the July 20th sampling date. In 2003 and 2004, petiole P concentrations were also adequate in mid-August, suggesting that P was not limiting (increasing P rate did not increase yield at these sites). In 2005 and 2006, petiole P concentration in some treatments fell below the adequate range in mid-August. However, petiole P concentration in some treatments did not consistently predict when yield responses to P application would occur at these two sites. In 2005, petiole P concentrations were greater than or equal to 0.16% in mid-August only in treatments receiving 60 and 90 lb P_2O_5/A, suggesting that P was not deficient in these treatments. However, a linear yield response was evident at this site with marketable yield increasing across the range of P fertilizer rates. Additional site-years of data are required to further assess petiole P criteria for Manitoba conditions.

Estimated P uptake by the potato plant shortly before tuber harvest averaged 16 lb P/A in 2004 and 2006, and 20 lb P/A in 2005. This estimate included vines, tubers, and recoverable roots plus stolons. Average P uptake in tubers was 12, 16, and 13 lb P/A in 2004, 2005, and 2006, respectively. Increasing P fertilizer rate did not result in a statistically significant ($p > 0.05$) increase in P uptake in 2005 and 2006 where all treatments had been sampled.

Detailed sampling of each plot (based on 10 cores/plot to 6 in.) following tuber harvest revealed a significant linear increase in Olsen P content in all years (**Table 2**). However, treatment effects were not always statistically significant using this sampling method. The difference in Olsen P level between the 90 lb P_2O_5/A treatment and the control ranged from 8 lb extra P/A in 2003 to 42 lb extra P/A in 2004.

Increasing P fertilizer rate resulted in a significant linear increase in marketable (> 3 oz) and total yield only in 2005, and a quadratic increase in marketable yield in 2006, even though all experimental sites would have received a recommendation to apply P fertilizer based on Manitoba guidelines. In the current study, the range of P fertilizer rates applied reflected provincial guidelines in Manitoba which recommend application of 90 to 110 lb P_2O_5/A for soils containing ≤ 10 ppm Olsen P, 70 to 80 lb P_2O_5/A for soils containing >10 and ≤15 ppm P, and 60 lb P_2O_5/A for soils containing >15 ppm P, assuming broadcast incorporation (Manitoba Agriculture, Food and Rural Initiatives, 2007). It should be noted, however, that P fertilizer recommendations for potato vary considerable among regions. Based on North Dakota guidelines (Dahnke et al., 1992), for example, P fertilizer would have been recommended in the current study only in 2004 (15 lb P_2O_5/A) and 2006 (75 lb P_2O_5/A) given the Olsen P level and average total yield at experimental sites. Comparatively higher P recommendations exist in other regions. In Wisconsin, for example, for fine- to medium-textured soils categorized as very low in P (<100 ppm P, Bray 1), 250 lb P_2O_5/A is recommended for a potato crop yielding 351 to 450 cwt/A; for soils testing low in P (100 to 160 ppm P), 180 lb P_2O_5/A is recommended (Laboski et al., 2006). Based on the Wisconsin guidelines, the probability of a yield increase to applied nutrients is >90% for soils in the very low category. In the current study, P application typically increased petiole P concentration at a given sampling date, however, petiole P criteria developed in potato-growing regions outside of Manitoba did not appear to consistently identify when positive yield responses to P application would occur. At all sites, increasing P rate also resulted in a linear increase in post-harvest soil test P levels in the surface 0 to 6 in. BC

Table 2. Effect of rate of P fertilizer application on Olsen P level (lb/A) for the 6 in. depth measured following tuber harvest in Manitoba.

P_2O_5 rate, lb/A	Year			
	2003	2004	2005	2006
0	37	31	32	28
30	45	43	45	35
60	43	58	62	39
90	45	73	64	42
Pr>f	0.0518	0.0001	0.0006	0.0366

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Managing Potassium for Organic Crop Production

By Robert Mikkelsen

An adequate K supply is essential for both organic and conventional crop production. Potassium is involved in many plant physiological reactions, including osmoregulation, protein synthesis, enzyme activation, and photosynthate translocation. The K balance on many farms is negative, where more K is removed in harvested crops than is returned again to the soil. An overview of commonly used K fertilizers for organic production is provided.

Potassium is an essential nutrient for plant growth, but it often receives less attention than N and P in many crop production systems. Many regions of the U.S.A. and all of the Canadian provinces remove more K during harvest than is returned to the soil in fertilizer and manure (**Figure 1**). In the U.S.A., an average of only 3 units of K is replaced as fertilizer and manure for every 4 units of K removed in crops, resulting in a depletion of nutrients from the soil and increasing occurrences of deficiency in many places.

Potassium is the soil cation required in the largest amount by plants, regardless of nutrient management philosophy.

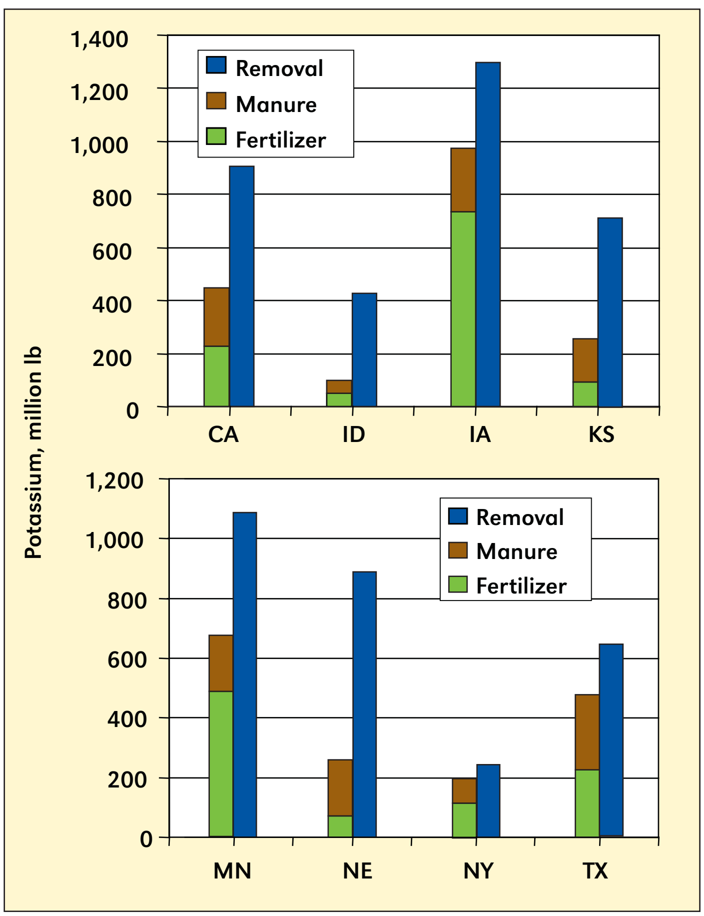


Figure 1. Annual balance of K inputs in fertilizer and recoverable manure compared with K removal in harvested crops in eight selected states: California (CA); Idaho (ID); Iowa (IA); Kansas (KS); Minnesota (MN); Nebraska (NE); New York (NY); Texas (TX).

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

Hay and forage crops can remove hundreds of pounds of K from the soil each year, placing a heavy demand on soil resources.

Large amounts of K are required to maintain plant health and vigor. Some specific roles of K in the plant include osmoregulation, internal cation/anion balance, enzyme activation, proper water relations, photosynthate translocation, and protein synthesis. Tolerance of external stress, such as frost, drought, heat, and high light intensity is enhanced with proper K nutrition. Stresses from disease and insect damage are also reduced with an adequate supply of K. Although there are no known harmful effects of K to the environment or to human health, the consequences of inadequate K can be severe for crop growth and efficient utilization of other nutrients, such as N and P. Maintenance of adequate K is essential for both organic and conventional crop production. More information and an extensive list of references are available at the website: **>www.ipni.net/organic/kreference<**.

Supplemental K is sometimes called "potash", a term that comes from an early production technique where K was leached from wood ashes and concentrated by evaporating the leachate in large iron pots. Clearly this practice is no longer practical and is not environmentally sustainable. This potash collection method depended on the tree roots to acquire soil K, which was then recovered after the wood was harvested and burned. Most K fertilizer, whether used in organic or conventional agriculture, comes from ancient marine salts, deposited as inland seas evaporated. This natural geological process is still visible in places such as the Great Salt Lake and the Dead Sea.

Organic Crop Production

The basic principles of plant nutrition are the same, whatever the production system used. Both organic and conventional production systems have many common objectives and generally work with the same basic global resources. While specific nutrient management techniques and options may vary between the two systems, the fundamental processes supporting soil fertility and plant nutrition do not change.

In general, the objectives of organic plant nutrition are to (i) work within natural systems and cycles, (ii) maintain or increase long-term soil fertility, (iii) use renewable resources as much as possible, and (iv) produce food that is safe, wholesome, and nutritious.

Which Organic Standards to Follow?

The use of approved nutrient sources is governed by a variety of regional, national, and international oversight organizations. Each organization maintains somewhat different standards and allows different materials to be used in their organic production systems as they individually interpret the intent of organic agricultural principles. As a result, a grower seeking advice on permissible organic materials should first know where the agricultural produce will be sold in order to meet the requirements of that market.

In general, regulations for mined K sources specify that they must not be processed, purified, or altered from their original form. However, there is disagreement between different certifying bodies over what specific materials can be used. Unfortunately, some of these restrictions on certain nutrient materials do not have solid scientific justification and their inclusion or exclusion on various lists should not be viewed as one material being more or less "safe" than another fertilizer material.

Using On-Farm Resources

There are many variations possible for successful K management in organic production systems. The largest differences occur on farms that produce both livestock and crops compared with farms that strictly produce crops for off-farm sale. In the mixed livestock/crop systems, the nutrition of the animals generally takes first priority and the residual manure is returned to surrounding cropland. In these cases, imported K in feed and bedding frequently exceeds the output in milk and meat products, sometimes leading to an accumulation of K in the surrounding fields that receive manure. Large losses of K may occur on these farms during manure storage and composting. Since excreted K mostly goes into urine, if this fraction is not effectively recovered it will not be returned to the field with the solid portion of the manure.

Crop rotations are a central part of organic production systems. While this practice can be helpful for supplying N when legume crops are included and may also reduce K leaching losses, rotations alone do not supply any additional K to the farm. Plant roots have been shown to enhance soil mineral weathering by depleting rhizosphere K and causing a shift in the K equilibrium. This shift can speed natural processes and enhance the rate of clay transformations. Subsoil K reserves may be important for some crop rotation systems where deep-rooted plants can extract K which may be subsequently used by shallow-rooted crops. While rotational crops may influence the availability of existing soil K, the removal of any plant material from the field continually depletes the soil nutrient supply and ultimately reduces long-term productivity.

Plant-available K is usually measured in the topsoil, but some deep-rooted plant species can take up considerable amounts of K from the subsoil. The contribution of subsoil K to the plant K requirement depends on the amount of plant-available K in the top and subsoil, potential root-limiting factors, and the root distribution pattern of the specific crop. Soil testing done near the soil surface will not account for this subsoil contribution to the K supply.

Table 1. Average K removal in the harvested portion of some common agronomic and horticultural crops (International Plant Nutrition Institute, 2007; Natural Resources Conservation Service, 2007).

Crop	Scientific name	K removal, lb K/ton
Alfalfa	*Medicago sativa*	45
Almond	*Prunus dulcis*	100
Corn grain	*Zea mays*	8
Corn silage	*Zea mays*	7
Potatoes	*Solanum tuberosum*	10
Spinach	*Spinacia oleracea*	11
Squash	*Cucurbita pepo*	10
Rice	*Oryza sativa*	8
Tomatoes	*Lycopersicon esculentum*	6
Wheat	*Triticum aestivum*	10

Moisture is based on marketing conventions.

Potassium Balance

Since off-farm sales will always lead to a removal of K and additional loss of K through leaching and runoff is inevitable, the potential of a cropping management system to replenish the K reserve is important. The use of farm budgets is useful for describing the nutrient flow within a farming system and to assist with nutrient planning for long-term rotations and mixed farming systems. Depending on a variety of factors, the on-farm budgets of N, P, and K on organic farms have been shown to range from a surplus to a deficit.

The demand for K by various crops has been well established by measuring the K concentration in the harvested portion of the crop (**Table 1**). However, much less attention has been paid to the rate at which K must be supplied to growing

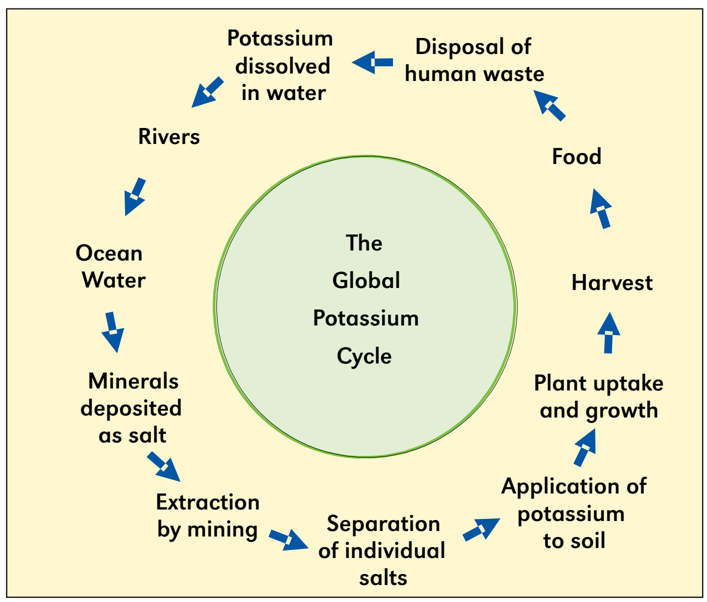


Figure 2. The global K cycle.

plants. Both the total amount required (quantity) and the rate of supply (intensity) are equally important. This concept is important for all crop growth, but requires special attention when using low-solubility nutrient sources that may provide an adequate amount of total K, but not at a rate sufficiently rapid to meet peak-demand periods of plant growth.

Potassium Release from Soil Minerals

The most common mineral sources of K in soils are feldspars and micas...soil minerals remaining from the primary parent material. Weathering of these primary minerals produces a range of secondary minerals that may also serve as a source of K in soil. These minerals include micaceous clays such as illite and vermiculite.

Crushed rocks and minerals have been evaluated as K sources in many field and greenhouse experiments. In general, plants are able to gain a very limited amount of K from minerals applied as biotite, phlogopite, muscovite, and nepheline. Feldspar K is not plant available without additional treatment or weathering.

The rate of K release from minerals is influenced by factors such as soil pH, temperature, moisture, microbial activity, the reactive surface area, and the type of vegetation. Therefore, a mineral that is somewhat effective as a K source in one condition may be ineffective in another environment.

Some soil minerals may act as a sink for removing K from solution. When K is adsorbed in the interlayer sites of illite, vermiculite and other smectite clays, the clay layers collapse and trap the K within the mineral lattice. This fixation process is relatively fast, while the release of this interlayer K is very slow. Non-exchangeable K should not be confused with mineral K, since non-exchangeable K is held between adjacent tetrahedral layers of clay, instead of being covalently bonded in mineral crystal structures.

Potassium Sources for Organic Production

Regular applications of soluble K, regardless of the source, will increase the concentration of K in the soil solution and the proportion of K on the cation exchange sites. All of the commonly used soluble K sources (including manures, composts, and green manures) contain this nutrient in the simple cationic K^+ form. Most soluble inorganic fertilizers and organic manures are virtually interchangeable as sources of K for plant nutrition. When using readily available forms of K, the overall goal of replacing the harvested K is generally more important than minor differences in the behavior of the K source. Any differences in plant performance are usually due to the accompanying anions, such as chloride (Cl^-) or sulfate (SO_4^{2-}) or the organic matter that may accompany the added K.

There is no general evidence that potassium sulfate (K_2SO_4) is more effective than potassium chloride (KCl) as a source of plant-available K, and both SO_4^{2-} and Cl^- provide essential nutrients that are required for plant health. Chloride is sometimes disparaged as being harmful to soil, but there is no evidence for this claim at typical rates of application. It has a well-documented role in improving plant health and prevention of a variety of plant diseases. Chloride-derived salinity was the same as sulfate-based salinity on its effect on common soil microbes (e.g. Li et al., 2006) and the addition of K decreased the harmful effects of salinity on soil microbial activity (Okur et al., 2002).

Organic production frequently occurs on smaller-sized farms where the use of organically approved K sources is feasible for maintaining soil fertility.

Approved and Restricted Potassium Sources

The National Organic Program in the U.S. and the Canadian General Standards Board classifies products as either allowed, restricted, or prohibited for use in organic production. Allowed products are permitted for organic production when applied as directed on the label. Restricted materials can only be applied for certain uses and under specific conditions. Prohibited products may never be used for organic production. The properties and value of these materials as sources of plant nutrients vary considerably. The following K sources are used sometimes for organic production.

Greensand has a very slow K release rate, which limits its nutritional benefit.

Greensand Greensand is the name commonly applied to a sandy rock or sediment containing a high percentage of the green mineral glauconite. Because of its K content (up to 5% K), greensand has been marketed for over 100 years as a natural fertilizer and soil conditioner. The very slow K release rate of greensand is touted to minimize the possibility of plant damage by fertilizer "burn", while the mineral's moisture retention may aid soil conditioning. However, the K release rate is too slow to provide any significant nutritional benefit to plants at realistic application rates. Soluble K is generally <0.1% of the total K present. Deposits of greensand are found in several states (including Arkansas and Texas), but the only active greensand mine in North America is located in New Jersey.

Langbeinite (Potassium-magnesium sulfate) This material ($K_2SO_4 \cdot MgSO_4$) is allowed as a nutrient source if it is used in the raw, crushed form without any further refinement or purification. Several excellent sources of this approved product are available for use with organic crop production. Langbeinite typically contains 18% K, 11% Mg, and 22% S in forms readily available for plant uptake. The major source of langbeinite in North America is from underground deposits in New Mexico.

Langbeinite is available from several sources. It is allowed as an organic nutrient source if used in the raw, crushed form without further refinement.

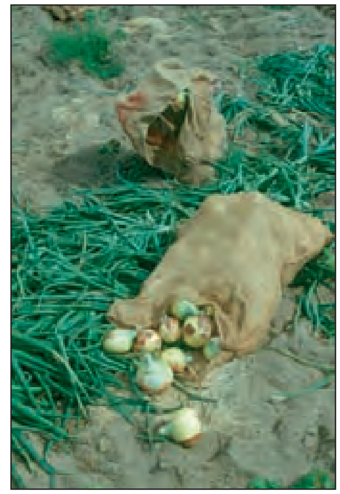
Manure and Compost Since these organic materials are extremely variable (based on their raw materials and their handling), they also contain highly variable K concentrations. Composted organic matter is generally allowed as a nutrient source. Raw manures have restrictions on the timing of their use, but the details depend on the certifying agency. The K in these organic materials is largely available for plant uptake, similar to approved inorganic sources. Repeated applications of large amounts of manure can result in K accumulation in the soil, which may lead to luxury consumption of K by the plant. A chemical analysis of the manure or compost composition is necessary in order to use these resources for maximum benefit. It may be helpful to consider where the compost or manure K is coming from, since neither composting nor animal digestion produces any nutrients.

Potassium Sulfate When K_2SO_4 is derived from natural sources, it is allowed for organic crop production. Much of the current production of organically approved K_2SO_4 in North America comes from the Great Salt Lake in Utah. It may not undergo further processing or purification after mining or evaporation, other than crushing and sieving. This product is not allowed in some European countries without special permission from the certifying agency. It generally contains approximately 40% K and 17% S.

Rock Powders Mined rocks, including ballast, biotite, mica, feldspars, granite and greensand are allowed without restriction. Tremendous variability exists in the K release rate from these mineral sources. Some of them are wholly unsuitable as K sources for plant nutrition due to their limited solubility and their heavy and bulky nature, while others may have value over long periods of time. In general, a smaller particle size translates to a greater surface area, reactivity, and weathering rate. Obtain information for specific rock materials before using.

Seaweed Since sea water contains an average of 0.4 g K/L, seaweed may accumulate up to several percent K. When harvested, seaweed biomass can be used directly as a K source or the soluble K may be extracted. These K sources are readily soluble and typically contain less that 2% K. While seaweed-derived products are excellent K sources, their low K content and high transportation costs can make it problematic for field-scale use, especially far from the harvesting area.

Sylvinite (Potassium Chloride) KCl is restricted in the USDA standards unless it is from a mined source (such as sylvinite) and undergoes no further processing. It must be applied in a manner that minimizes Cl accumulation in the soil. Generally, KCl should only be used after consultation with the certifying agency. The Canadian GSB has included KCl on the "Permitted Substances List" for organic food production systems. Unprocessed sylvinite often contains approximately 17% K.



Production of high quality crops is sustained with attention to proper soil nutrition.

Wood Ash Ash from hardwood trees served as one of the earliest sources of K for building soil fertility. This highly variable material is composed of the elements initially present in the wood which were not volatilized when burned. Wood ash is an alkaline material, with a pH ranging from 9 to 13, and has a liming effect of between 8 and 90% of the total neutralizing value of commercial limestone. In terms of commercial fertilizer, average wood ash would have an analysis of approximately 0% N, 1% P, and 4% K. The use of ash derived from manures, biosolids, coal, and some substances is prohibited for organic production. Check with the certifying organization prior to applying ash to soil.

Conclusions

Growers using organic production practices, like all growers, have need for an adequate supply of soil K to sustain healthy and high-yielding crops. There are many excellent sources of K that are available for replacing the nutrients removed from the soil in harvested crops. Failure to maintain adequate K in the rootzone will result in poor water use efficiency, greater pest problems, decreased harvest quality, and reduced yields. Regular soil testing for K is the key for establishing the requirement for fertilization. If a need for supplemental K exists, organic producers generally should first consider locally available K resources and supplement with mineral sources. The expense of transporting and applying low nutrient content amendments must also be considered. BC

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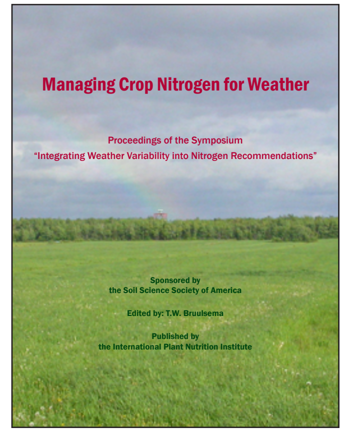
For more information and a list of references, visit the website at **>www.ipni.net/organic/kreferences<**.

References

Li, X., F. Li, B. Singh, and Z. Rengel. 2006. Biol. Fertility Soils. 42:366-370.
Mikkelsen, R.L. 2007. Hort Technology. 17: 455-460.
Okur, N., M. Çengel, and S. Göçmez. 2002. Acta Hort. 573: 189-194.

Proceedings of the Symposium "Integrating Weather Variability into Nitrogen Recommendations"



The weather controls a great deal of the crop response to nitrogen. The contents of a new publication titled Managing Crop Nitrogen for Weather, based on the proceedings of a symposium at the 2006 meeting of the Soil Science Society of America (SSSA), provide details of experimental data and experiences of those engaged in efforts to improve prediction of crop nitrogen needs in response to weather conditions.

The papers contained in this 132-page publication were originally presented at the Symposium "Integrating Weather Variability into Nitrogen Recommendations." Thirteen of the original presentations from the Symposium are contained in the publication, plus abstracts of others. The authors are from several different countries and are recognized scientific authorities on their topics. The International Plant Nutrition Institute (IPNI) published the proceedings.

The publication is paper-bound, 8½ x 11 in., and contains some color. It is available for purchase from IPNI for US$50.00 plus shipping/handling.

Contact:
Circulation Department, IPNI,
3500 Parkway Lane, Suite 550,
Norcross, GA 30092-2806 U.S.A.
Phone: 770-825-8082
Fax: 770-448-0439
E-mail: circulation@ipni.net

The publication may also be ordered online at the IPNI website: **www.ipni.net/weather** BC

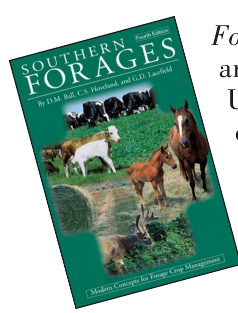
Posters Feature Forage Legumes and Grasses/ *Southern Forages* Book Now in Fourth Edition

Two educational 24 x 30-in. posters, *Forages Legumes* and *Forage Grasses*, are now available from IPNI. Each poster features color photographs of 30 species of important forage plants, along with descriptive text on seeding/establishment, fertility needs, pest considerations, and other practical tips.

The posters were prepared by the authors of the popular book, *Southern Forages*. They are Dr. Don Ball, Auburn University; Dr. Carl Hoveland, University of Georgia; and Dr. Garry Lacefield, University of Kentucky. The book was first published in 1991 and has become a standard among farmers, educators, horse owners, individuals managing wildlife plots, and many others.

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

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



The Fourth Edition of the book *Southern Forages* was published by IPNI in early 2007 and is now available for US$30.00 plus US$4.00 shipping and handling for a single copy. Discounts are available on larger quantities.

For more information and cost details, contact: Circulation Department, IPNI, 3500 Parkway Lane, Suite 550, Norcross GA 30092-2806; phone 770-825-8082; fax 770-448-0439; e-mail: circulation@ipni.net; website: **www.ipni.net/sf**. BC

Eurípedes Malavolta, 1926-2008: Memoriam

Dr. Malavolta

Dr. Eurípedes Malavolta, one of the most recognized Brazilian plant nutrition scientists, died February 19 in Piracicaba, Brazil. He graduated in Agronomy from the University of São Paulo (USP), School of Agriculture Luiz de Queiroz, in 1948 and began his career as Professor in the same Institution. Dr. Malavolta earned several degrees until becoming full Professor in 1958. He served as director from 1964 to 1970 and also served as a visiting scientist in institutions around the world.

Through his career he was distinguished with several honors, including member of the Brazilian Academy of Science in 1964 and National Scientific Merit Degree in 1998. He also represented Brazil in the United Nations as a consultant in science and technology for the benefit of less developed countries of the world.

He retired in 1984, but continued to serve USP in the Center of Nuclear Energy in Agriculture as a permissionary researcher until 3 days before his death. Through his career, he authored 45 books which were translated from Portuguese to several other languages, including Spanish, English, Hindi, and Chinese. Highly recognized by his enormous dedication to education in all levels, Prof. Malavolta published 823 papers and served as adviser for 40 dissertations and 64 Ph.D. theses.

Among several technical contributions, perhaps one of the most recognized worldwide was his work with sulfur, not only concerning increase in crop yield but most especially related to the importance of this nutrient on food protein quality.

In recognition for all his accomplishments, the new IPNI Brazil Program Director, Dr. Luís Ignácio Prochnow, invited Dr. Malavolta last December to write the main article of the March issue of the Brazilian version of *Better Crops (Informações Agronômicas)*. The article, entitled "The Future of Plant Nutrition Concerning Agronomic, Economic, and Environmental Issues", was nearly finished and is being published in his memory. BC

Conversion Factors for U.S. System and Metric Units

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

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

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

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

Other Useful Conversion Factors

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

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

The New Geography of Plant Nutrition

Farmers today have a new set of tools to help them deal with the challenges of nutrient management decisions. Substantial fluctuations in prices for fertilizer and other inputs, and in prices received for crops sold, have made these tools even more valuable. Beyond the economic incentives, these tools also help optimize agronomic plans for the crop production system, and make important contributions to improving our stewardship of soil, water, and air resources.

GIS-based record keeping. Good records serve to document past and current cropping practices and help design plans for future seasons. Building records into a Geographic Information System (GIS) allows for more details to be kept about the variability within fields, important to fine-tuning inputs for the future.

Soil testing. New application options enhance the value of traditional soil tests. Systematic geographically-referenced sampling provides ability to map spatial variability in soil nutrient supply and guide variable-rate application to efficiently distribute fertilizers precisely where they are needed.

Variable-rate application. The value of variable-rate application is increased as fertilizer prices and grain prices increase. Being able to put fertilizer dollars where they will be most effective is always a good idea, but with higher prices the economic incentive is much greater. When a uniform rate is used, parts of the field get nutrient levels built beyond where there is an economic response and/or other parts do not get enough to reach optimum levels. And there are the added potential benefits to the environment of applying nutrients only where they are needed.

Digital soil survey. The soil is the most basic resource for production, and the main manageable source of variability within the field. Geo-referenced digital soil surveys are now available for almost every field and contain a great wealth of information about each soil type in a field. This information can be incorporated into the field's GIS records and used with numerous analytical and decision-aid software tools to help make management decisions.

Yield monitors. Yield monitors are now available for most major commodity crops, providing an accurate measurement of yield and its variability across the field. With GIS analysis tools, yield data can be related to the geo-referenced data on inputs, weather, pests and other scouting observations, remote sensing imagery, and digital soil survey. Compared over time, yield maps can identify yield trends and profitability of different areas of the field. Analyzing the various databases may help identify areas of a field that should be taken out of production, and others that may warrant more intensive management. Yield variability means variability in nutrient uptake and removal, and can help better define variability in maintenance fertilizer needs.

Better-informed decisions. With a growing data base of geo-referenced information to draw upon, farmers and their advisers can fine-tune management decisions to move closer to optimum levels of inputs to produce the optimum yields for maximum profit. Embracing the technology to collect and manage information, and to make better-informed decisions on nutrient management is the first step in keeping a production system profitable for each field. Similar technologies for other inputs can help further enhance profits.

These technologies for getting the right rate of the right inputs in the right place at the right time have demonstrated the increased value of better information. The cost of putting on too much fertilizer can be avoided. Perhaps more important, the greater cost (loss) from not putting on enough in parts of a field can be avoided. Using these geo-referencing tools and technologies also helps farmers reduce their contribution to environmental problems and protect the production resources that will sustain productivity for future generations.

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