BETTER CROPS WITH PLANT FOOD

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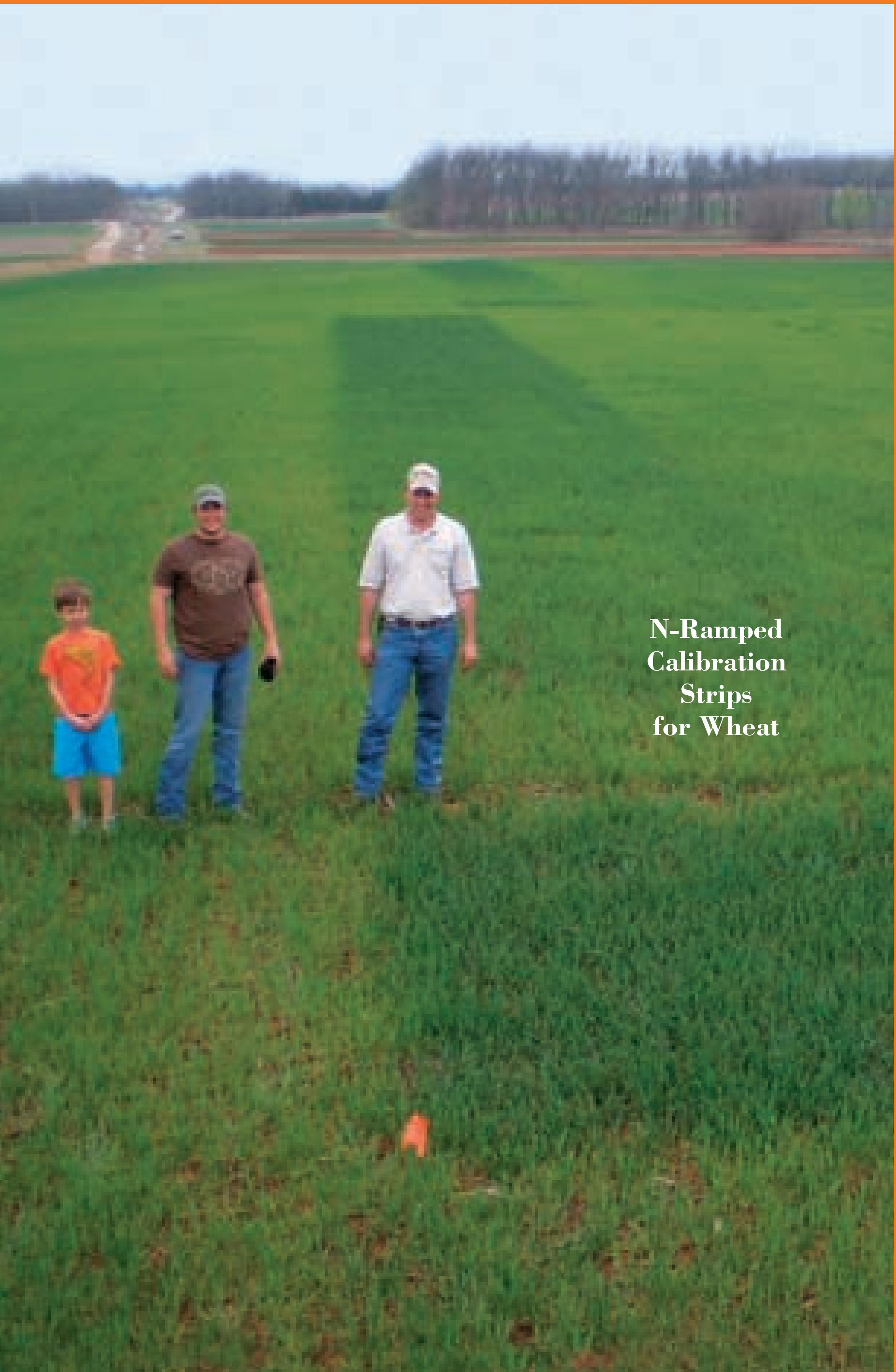

N-Ramped Calibration Strips for Wheat

In This Issue...

Nutrient Accumulation Rates of Potatoes

N and S for Improved Bread Wheat Quality in Humid Environments

Balancing Fertilizer Use and Profit in Asia's Irrigated Rice Systems

Plus...

Winners of IPNI Crop Nutrient Deficiency Photo Contest

...and much more

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Vol. XCII (92) 2008, No. 1

Our cover: Large photo was taken at Efaw Research Station, Stillwater, Oklahoma. Pictured from left to right are Chris Raun, Clint Dotson, and Jason Lawles.
Photo by Dr. Bill Raun, Oklahoma State University

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IPNI Science Award Goes to Dr. M.S. Aulakh of India

Dr. M.S. Aulakh

The International Plant Nutrition Institute (IPNI) has named Dr. Milkha Singh Aulakh of Punjab Agricultural University (PAU), India, as the winner of the 2007 IPNI Science Award. Dr. Aulakh, a Senior Soil Chemist and Professor, is presently Additional Director of Research at Ludhiana, PAU. He receives a special plaque plus a monetary award of US$5,000.00 (five thousand dollars).

"This is the first time we have presented the new IPNI Science Award, and we are honored to announce that Dr. Aulakh has been selected as the recipient," said Dr. Terry L. Roberts, President of IPNI. "He has made distinguished contributions in global ecological intensification as related to crop production, with important achievements in research, extension, and education."

Dr. Roberts also acknowledged other outstanding candidates for the award, and encouraged future nominations of qualified scientists. Private or public sector agronomists, crop scientists, and soil scientists from all countries are eligible for nomination.

Born in Amritsar, India, Dr. Aulakh received his B.Sc. in Agriculture in 1972 at Guru Nanak Dev University, and his M.Sc. in Soil Science at PAU in 1974, then joined PAU as a Research Assistant. After completing his Ph.D. in Soil Science in 1984 at the University of Saskatchewan, Canada, he returned to India. Later, he was a Postdoctoral Research Fellow and Fulbright Scholar at the University of Nebraska-Lincoln, and visiting scientist with USDA-ARS in 1989-90. In 1997-99, Dr. Aulakh was Project Scientist at the International Rice Research Institute (IRRI) in the Philippines, and Collaborating Scientist at Frounhofer Institute for Atmospheric Environmental Research and at University of Freiburg in Germany. He also served as the Principal Investigator on a 6-year USDA-OICD project (1991-96) and is currently Chief Scientific Investigator of the prestigious 5-year (2004-2009) FAO/IAEA Coordinated Research Project on Integrated Soil, Water and Nutrient Management for Conservation Agriculture.

Dr. Aulakh's work at PAU has a focus on balanced and integrated nutrient management for optimum yields and quality of field crops, nutrient transformations and losses in soils, and associated environmental impacts such as emissions of greenhouse gases, carbon sequestration, and leaching of nitrates and phosphates. He played a pivotal role in identifying widespread sulfur deficiency in subtropical soils, delineation of sulfur-deficient areas, and development of diagnostic tools for assessing sulfur-adequacy in soil and plants.

Well known and respected in academic as well as industry groups, Dr. Aulakh has published 90 research papers in 30 national and international journals, 40 book chapters and scientific reviews, and 80 conference proceedings and technology transfer publications. He is a Fellow of the National Academy of Agricultural Sciences, Indian Society of Soil Science, and Punjab Academy of Sciences, and a Member of the International Union of Soil Sciences. Since 2000, he has served on the Editorial Board of the international journal *Biology & Fertility of Soils* published by Springer. Dr. Aulakh is a recipient of the Canadian Commonwealth Fellowship (1980-83), Plant Nutrient Sulphur Research Award by The Sulphur Institute of Washington, D.C. (1990), International Crop Nutrition Award by International Fertilizer Industry Association, Paris, France (2001), Alumni Honour Award by the University of Saskatchewan, Saskatoon, Canada (2002), and Pierre Becker Memorial Award by Fertilizer International and British Sulphur, London, UK (2005). At the national level, he is decorated with several prestigious awards, including the Rafi Ahmad Kidwai Memorial Prize of Indian Council of Agricultural Research (ICAR), Silver Jubilee Award by the Fertilizer Association of India (FAI) in 1987, Outstanding Research Award by National Fertilizers Limited in 1989, Hari Om Ashram Trust Award for Agricultural Sciences Research by ICAR in 1990, Twelfth International Congress Commemoration Award by Indian Society of Soil Science in 1995, and first IMPHOS-FAI Award instituted by World Phosphate Institute, Morocco, in 2002.

Dr. Aulakh is editor of a new book titled *Integrated Nutrient Management for Sustainable Crop Production*, which takes a global view of challenges faced in 10 geographically and demographically diverse regions of the world.

The IPNI Science Award is intended to recognize outstanding achievements in research, extension, or education, with focus on efficient and effective management of plant nutrients and their positive interaction in fully integrated crop production that enhance yield potential. Such systems improve net returns, lower unit costs of production, and maintain or improve environmental quality. The recipient is selected by a committee of noted international authorities.

More information and nomination forms for the 2008 IPNI Science Award are available from the headquarters or regional offices of the organization, or from the website: **www.ipni.net/awards**. BC

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<**

Measuring Nutrient Accumulation Rates of Potatoes—Tools for Better Management

By Don Horneck and Carl Rosen

Fertilizer can be managed more precisely when both the total nutrient demand and the daily rate of nutrient accumulation of the crop are known. The results of two studies are presented for high-yielding irrigated potatoes grown in Minnesota and in Oregon. Closely matching nutrient availability with crop demand is essential for producing profitable yields of high quality potatoes, while minimizing unwanted nutrient losses to the environment.

Nutrient applications are made on the basis of meeting the plant demand and the existing supply of soil nutrients. But it can be a challenge to precisely meet these nutritional needs. Not only must the total quantities of nutrients be present during the growing season, they must be available at the time they are required by the developing plant. Meeting the nutrient demand may be relatively simple with a turf crop, for example, where seasonal growth rates are fairly constant. However, for other crops such as potatoes, timing nutrient application can be a challenge.

Potatoes require an optimal supply of nutrients throughout the growing season to sustain their growth and tuber development. Their exact nutrient demand is a function of many factors such as the growth rate, the growth stage, the climatic conditions, and the potato variety. Additional factors such as yield goals, economic return, and environmental impacts also need to be considered. Since either deficient or excessive plant nutrition can reduce tuber bulking and quality, fertilizer management must be done with care.

Meeting the seasonal nutrient demand for potatoes is aided by several management tools. These include pre-plant soil testing to estimate future nutrient availability, in-season tissue testing, and mid-season application of nutrients to address any emerging nutrient shortages as the crop develops.

One useful guide for fertilization is knowledge of the nutrient accumulation pattern (plant concentration multiplied by the dry matter content) during the growing season (**Table 1**). Knowledge of the total seasonal demand and the daily nutrient requirement provides a useful guide for both early season fertilization and mid-season adjustments. When graphed, patterns of nutrient uptake generally follow an "***S***-shaped" type of curve. Nutrient uptake is generally most rapid during the time of tuber initiation and bulking, then tapering off during tuber maturation later in the growing season

Table 1. Typical nutrient accumulation in vines and tubers of a 400 to 500 cwt/A Russet potato crop and the general maximum daily uptake rate for the plant during the growing season.

	Total plant uptake, lb/A		Peak daily uptake rate, lb/A/day
	Vines	Tubers	
Nitrogen	140	210	4 to 7
Phosphorus	10	29	0.4 to 0.9
Potassium	275	240	5 to 14
Sulfur	12	22	0.1 to 0.6

Estimates based on data presented here and Stark et al. (2004).

Yield and quality can suffer from either over- or under-supply of N.

The results of two studies are presented where potatoes were grown with non-limiting water and optimal nutritional conditions. The study conducted in Minnesota focused primarily on N, while the study in Oregon collected data on several of the essential plant nutrients.

Minnesota

Russet Burbank potatoes were grown on a sandy soil (Hubbard loamy sand, Entic Hapludolls) on the Sand Plain Research Farm near Becker, Minnesota. The potatoes were fertilized with 240 lb N/A applied in three split applications and irrigated as needed. Samples of vine and tuber were collected seven times during the growing season, weighed, and analyzed for total N. These results are a portion of the data collected in the larger study (Rosen et. al., 1993; Zebarth and Rosen, 2007).

Total dry matter accumulation was most rapid during the period of 40 to 100 days after planting, corresponding to the periods of tuber initiation and early tuber bulking (**Figure 1**). Since the tubers account for up to 90% of the total dry weight at the end of the season, it is important to maintain favorable growing conditions through the entire season to support their growth.

The majority of N acquired by the plant preceded the peak of vine and tuber growth. As tuber development entered the bulking stage, the initially large fraction of N in the vines continually declined until harvest as N was retranslocated to the tubers (**Figure 2**). Potato plants have already taken up over 50% of their total N requirement by the time tuber bulking

Abbreviations and notes for this article: N = nitrogen; P = phosphorus; K = potassium; K_2SO_4 = potassium sulfate; KCl = potassium chloride or muriate of potash.

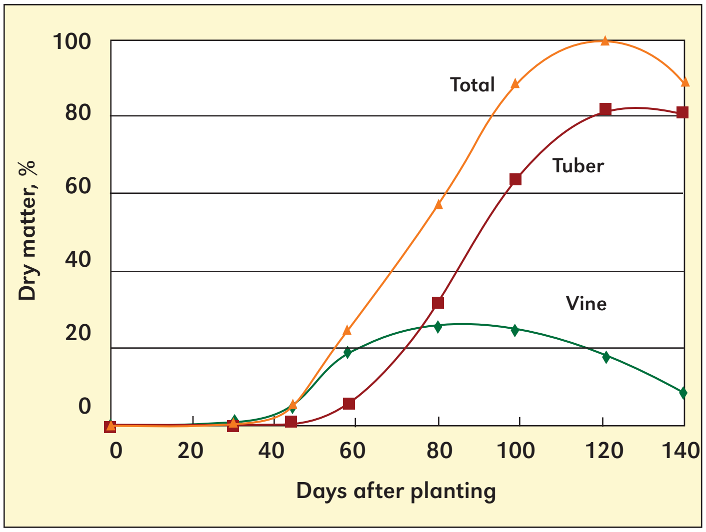

Figure 1. Dry matter accumulation and partitioning by Russet Burbank potato during the growing season near Becker, Minnesota (expressed as percent of total seasonal biomass).

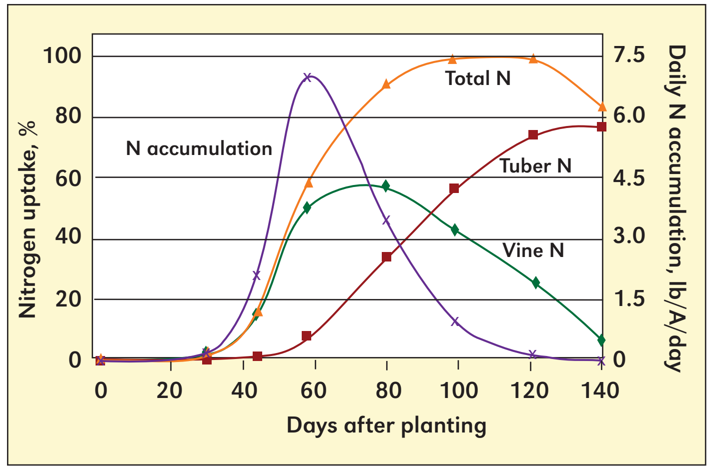

Figure 2. Seasonal N accumulation by Russet Burbank potato vines, tubers, and whole plants (left axis) and the average daily N accumulation rate (right axis) growing near Becker, Minnesota. Nitrogen uptake is expressed as a percent of the total seasonal accumulation.

begins, highlighting the importance of an adequate supply of early season N.

Oregon

Potatoes (Russet Burbank) were grown on a Quincy fine sand soil (Xeric Torripsamments) with non-limiting nutrition and irrigation near Hermiston, Oregon. The potatoes received a total of 325 lb N/A (16% preplant), 220 lb P_2O_5/A (45% preplant), and 240 lb K_2O/A (95% preplant). Nutrients that were not applied preplant were added through the irrigation system during the growing season. Plants were harvested six times and partitioned between vines and tubers. Plant tissue was analyzed for dry matter and nutrient content. Taking the first derivative of the uptake data calculates the daily average accumulation rate between sampling dates.

The pattern of dry matter production was similar to the results of the Minnesota work, where a maximum daily growth rate (DM) was measured 90 to 100 days after planting (**Figure 3**). This maximum growth period occurred 20 to 30 days following the phase of maximum nutrient accumulation. A shortage of essential nutrients during this peak period of uptake would likely have impaired the plant growth occurring several weeks later. This observation that maximum nutrient uptake always preceded maximum growth is a reminder that when nutrient deficiencies occur in the foliage, it is likely that yield losses have already occurred.

Nutrition and irrigation were non-limiting in the Oregon Studies. Nutrients not applied preplant were applied through the irrigation system.

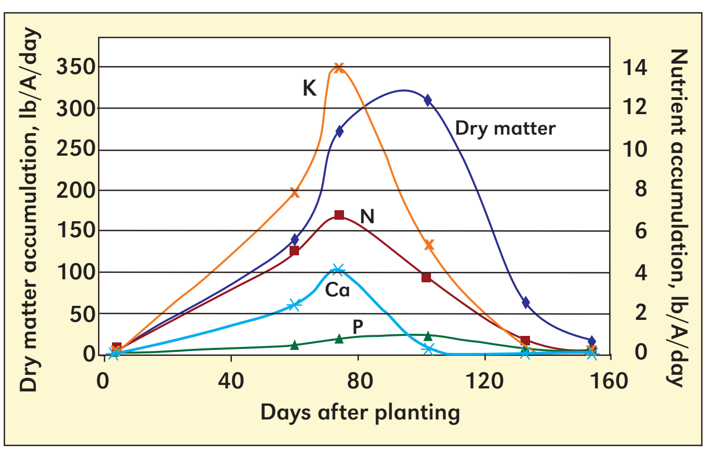

Figure 3. Daily growth rates (left axis) and daily nutrient accumulation (right axis) by Russet Burbank potatoes during the growing season near Hermiston, Oregon.

The total and daily accumulation of N, P, and K is shown in **Figure 4**. All three of these nutrients have similar patterns of uptake during the growing season. However, the peak period of uptake may occur over a longer time for P than for N and K.

Summary

Nitrogen: Approximately two-thirds of the total plant N is accumulated in the first few months following planting. Therefore, an adequate availability of N must be maintained in the root zone to support this rapid uptake. This is not a simple task, since excessive early season N can increase the susceptibility to brown center, hollow heart, and delays in maturation, while excessive N during the late season can reduce the specific gravity of the tuber and the skin set. Petiole testing is frequently useful for monitoring N availability and determining the need for supplemental fertilization.

During the time of maximum growth during the midsummer, the plants accumulated up to a maximum of 7 lb N/A/day.

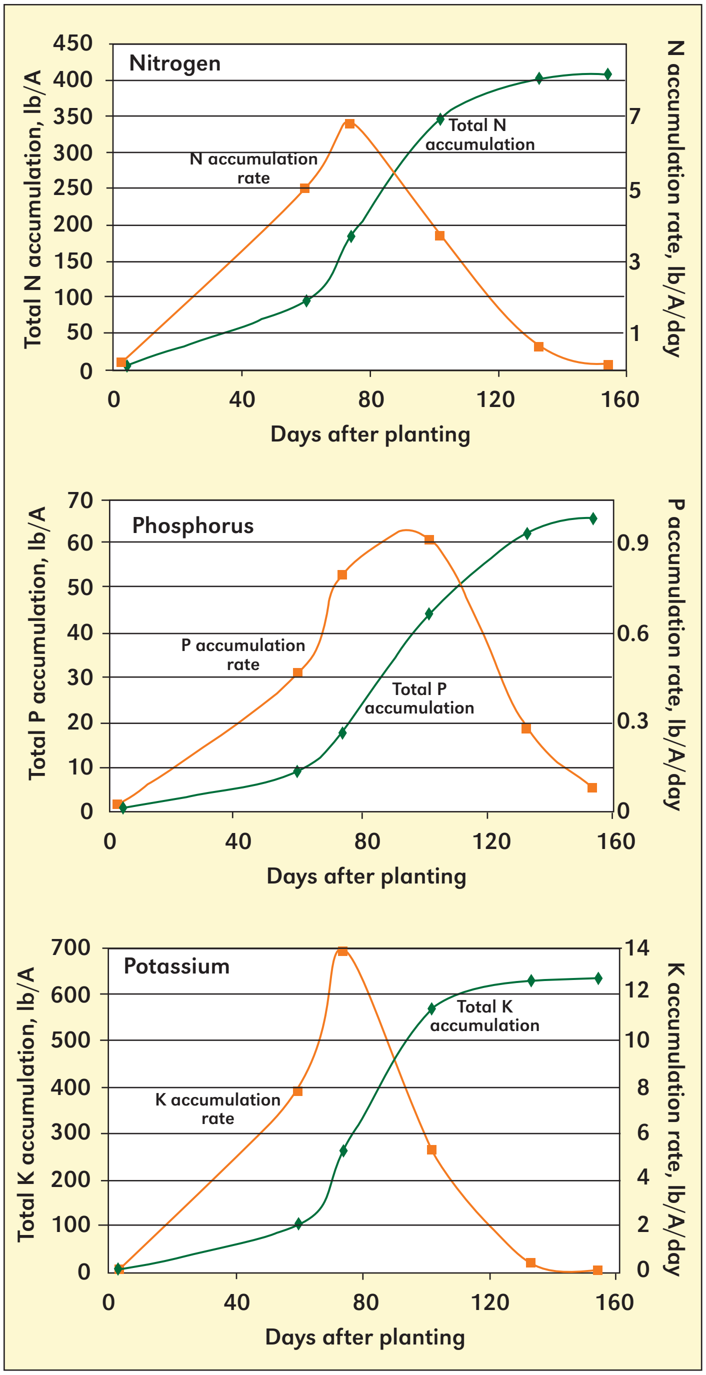

Figure 4. Total (left axis) and daily rate (right axis) of N, P, and K accumulation by Russet Burbank potatoes grown with non-limiting nutrition and water near Hermiston, Oregon.

This large amount of N can come from N already in the soil, N released from organic matter, N in the irrigation water, or from fertilization. Since yield and quality suffer when N is over- or under-supplied, close monitoring of the plant N status is recommended.

Phosphorus: The rate of plant P uptake generally peaks during the middle of the growing season, with a daily demand of between 0.4 and 0.9 lb P/A/day depending on the variety and location. The amount of P present in the soil solution at any time is generally low and is regulated by the buffering capacity of the particular soil. Each soil has a different capacity to replenish the roots with soluble P from mineral and organic sources.

When P concentrations are inadequate to meet peak demands, tuber size and yield are diminished. Fertilizer P is generally applied prior to planting based on soil tests, but monitoring petiole P concentrations is also common for determining the need for additional mid-season P. Sprinkler application of soluble P can be effective for supplementing the P supply if active roots are very near the soil surface. With a full plant canopy, potato root density will typically be high near the soil surface. This is important since P fertilizer applied through the sprinkler system rarely moves more than a few inches into the soil. A week or two may be required before a response to added P is measurable, so applications should be made in advance of possible deficiencies.

Potassium: Potatoes typically accumulate more K than any other nutrient. During the peak uptake period, daily accumulation rates can exceed 5 to 14 lb K/A/day, and over 600 lb K/A was accumulated by the crop. An adequate supply of K can help prevent a variety of tuber quality defects, such as blackspot bruising, low specific gravity, and poor storage quality. Excessively high K may also be detrimental and should be avoided. Potassium application rates should be based on soil testing and crop removal rates.

The majority of K fertilizer is usually applied prior to planting. At typical application rates, there is no consistent difference between K sources. At high K application rates, K_2SO_4 or a blend of KCl and K_2SO_4 may tend to produce slightly larger potato yields with higher specific gravity compared with KCl alone. The timing and rate of application, as well as the product blend, are important considerations when making K applications to potatoes. BC

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IPNI Staff Honored with Awards at 2007 ASA-CSSA-SSSA Annual Meetings

Three scientific staff members of IPNI were recognized for their career achievements during the recent annual meetings of the American Society of Agronomy-Crops Science Society of America-Soil Science Society of America (ASA-CSSA-SSSA). They are:

- Dr. Tom Bruulsema, elected Fellow of ASA
- Dr. Fernando García, Agronomic Industry Award
- Dr. Rob Mikkelsen, elected Fellow of SSSA

Dr. Bruulsema is Northeast Region Director in the IPNI North American Program, based at Guelph, Ontario. He received a B.S. in agriculture and M.S. in crop science at the University of Guelph and Ph.D. in soil science from Cornell University. His research program focuses on the benefits of plant nutrition for the crops of the region, and his educational activities feature responsible, science-based use of fertilizer nutrients. He currently serves as President of the Canadian Society of Agronomy and served as President of the ASA-SSSA Northeastern Branch from 1999-2002. Dr. Bruulsema has also been active in the Certified Crop Adviser (CCA) Program, as Chair of the International (2001-2004) and Ontario (1999-2000) boards. He currently represents CCA on the ASA Board of Directors. He also has experience in international agriculture, having served 4 years with the Mennonite Central Committee as research agronomist in Bangladesh.

Dr. Bruulsema, right, accepted the Fellow Award from ASA President Dr. Jerry Hatfield.

Dr. García is Director of the Latin America-Southern Cone Program, based in Buenos Aires, Argentina. He is the first winner of the Agronomic Industry Award from outside North America. Dr. García is a native of Argentina and earned his B.S. degree from the University of Buenos Aires and his M.S. and Ph.D. from Kansas State University. He joined the staff of PPI (now IPNI) in 1998 and coordinates an active program of research support and educational programs on soil fertility and management, crop nutrition management, and fertilization in the Southern Cone countries of Argentina, Bolivia, Chile, Paraguay, and Uruguay. Dr. García has developed a highly effective program working with national agricultural institutes and universities, as well as with farmers and industry groups. He has authored or co-authored more than 100 extension and research publications, 16 refereed journal articles, and 55 abstracts. Dr. García is the current president of the Soil Science Association of Argentina (AACS). He is a member of ASA, SSSA, the International Fertiliser Society, and the Soil Science Societies of Bolivia and Chile.

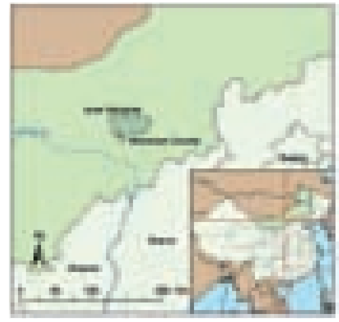
Dr. García received the ASA Agronomic Industry Award.

Dr. Mikkelsen is the Western Region Director in the IPNI North American Program, based at Merced, California. He earned his B.S. degree from Brigham Young University and his Ph.D. from the University of California, Riverside. Dr. Mikkelsen worked as a Research Scientist at the National Fertilizer Development Center of the Tennessee Valley Authority from 1987 to 1991. He was responsible for nutrient management issues involving fertilizers and irrigation, and received a patent for new fertilizer innovations. He joined the Soil Science Faculty at North Carolina State University (NCSU) in 1991, where he was active in graduate education. His research focused on managing fertilizers and manures in cropping systems to maximize nutrient efficiency and productivity. He joined the staff of PPI (now IPNI) in 2002 and works throughout the Western U.S. and Canada to promote science-based education and research programs related to plant nutrient use. He is an active leader in many regional and national professional organizations. He currently represents soil fertility and plant nutrition issues on the Soil Science Society of America Board of Directors. He has served on numerous international editorial boards, including his current work with the Soil Science Society of America Journal. Dr. Mikkelsen was elected as a Fellow of ASA in 2005. BC

Dr. Mikkelsen, center, received the Fellow Award from SSSA President Dr. Rattan Lal, right. The President of Bangladesh, Iajuddin Ahmed (at left), was guest lecturer at the ceremony.

Characterizing the Response of Rainfed Rapeseed to Fertilizer Application

By Yu Duan, Debao Tuo, Peiyi Zhao, and Huanchun Li



Field experiments on the response of rainfed rapeseed to N, P, and K fertilizer application showed significant yield increases due to their balanced use. Recovery efficiencies averaged 31% for N, 12% for P, and 35% for K. Each 100 kg of rapeseed removed 5.5 kg N, 1.7 kg P_2O_5, and 4.5 kg K_2O, respectively.

Rapeseed is one of the most important oil crops in China. In 2006, the rapeseed area planted was 6.9 million hectares (M ha) supporting a production of 12.7 M tonnes (t), or 41% of China's total oil production. The Inner Mongolia Autonomous Region (IMAR) has 210,000 ha planted annually and its production in 2006 was 250,000 t (China Agriculture Statistical Report, 2006). The average yield of rapeseed is about 1.2 t/ha, with the range of 0.7 to 3.0 t/ha. This crop is often planted in low fertility soils with little fertilizer input (15 to 30 kg/ha of diammonium phosphate). Given this modest level of management, there is great potential to increase rapeseed yields by utilizing the well understood principles of balanced fertilization. This research was aimed at characterizing crop nutrient demand and fertilizer use efficiency under a production system with higher yield potential.

Field experiments were carried out from 2002 to 2005 in Dongtucheng Town, Wuchuan County, IMAR. The IMAR has a temperate continental climate. Spring is warm and windy; summer is short and hot with many rainy days; autumn usually sees early frost and plummeting temperature into winter. The region has 80 to 150 frost-free days depending on location. The IMAR has a sharp annual rainfall gradient, from 600 mm in the east to less than 100 mm in the west. Most of the rainfall occurs from May to September, coinciding with high temperatures (Yu et al., 2004). During the 4 years of study, the site had growing season precipitation ranging between 162 to 317 mm and accumulated growing degree units (GDUs) between 1,888 to 2,137 (**Table 1**). Selected soil properties (0 to 20 cm depth) are shown in **Table 2**.

Table 1. Precipitation and growing degree unit (GDU) accumulation in the growing seasons from 2002 to 2005.

	Precipitation, mm				Accumulative GDU, °C			
	2002	2003	2004	2005	2002	2003	2004	2005
May	30	54	68	33	379	405	339	376
June	62	42	43	24	538	460	505	579
July	20	100	84	46	608	564	569	630
August	50	121	104	108	574	518	475	552
Total	162	317	299	211	2,099	1,947	1,888	2,137

Table 2. Soil properties at experimental sites

Year	pH	OM %	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
			mg/L										
2002	8.3	0.9	9.1	13.2	75.8	3,256	175	9.1	1.0	2.0	11.4	9.1	0.7
2003	8.4	1.1	10.3	14.8	94.0	3,186	194	1.6	1.8	3.5	22.0	12.4	1.7
2004	8.4	1.0	58.0	13.5	46.9	3,008	159	2.0	3.4	1.1	6.4	6.6	0.6
2005	8.4	1.2	34.2	11.2	54.8	3,218	193	8.7	2.8	1.8	16.2	4.4	1.0

Note: Soil was analyzed using ASI method in China-Canada Cooperative Lab in Beijing

Research in Inner Mongolia quantified rapeseed response to N, P, and K fertilizer under a more intensive production system.

The series of experiments compared four treatments including an NPK 'optimum' (OPT), and treatments excluding N (OPT-N), P (OPT-P), and K (OPT-K). Plots were arranged in a randomized complete block design with three replicates. Rates within the OPT were recommended based on soil analysis (Hunter and Portch, 2002) and a realisitic yield target of 2 to 2.5 t/ha (**Table 3**). Fertilizer sources were urea, triple superphosphate, and potassium chloride. All fertilizers were band applied before sowing in the spring at a 15 cm depth. The rapeseed variety was Dahuang, a mustard-type (*Brassica juncea Czern. et Coss*), and a major variety planted in IMAR. This variety has multiple branches and a prolonged flowering period and can be harvested 100 days after seeding. Seed and straw samples were collected at harvest from 2002 to 2005 and total N, P, and K contents were analyzed and total nutrient accumulation was determined.

Table 3. Nutrients applied in rapeseed experiments, kg/ha.

	2002	2003	2004	2005
N	64	0	45	45
P_2O_5	45	58	30	30
K_2O	45	56	30	30

Despite large year-to-year variations in yield, balanced use of NPK application was

Abbreviations and notes for this article: N = nitrogen; P = phosphorus; K = potassium; AE = agronomic efficiency; RE = recovery efficiency.

most consistent at producing highest yields compared to the three nutrient omission treatments (**Table 4**). The main limiting factor in rapeseed production was N, followed by P, and then K. Yields under the OPT were 13 to 26% (mean = 18%) higher than the OPT-N treatment, 4 to 18% (mean = 13%) higher than the OPT-P treatment, and 3 to 16% (mean = 7%) higher than the OPT-K treatment.

There was a significant difference in rapeseed yield between years (**Table 4**). In 2002, there was sufficient rain over the year with more rain in June improving crop growth, and good drying conditions in July promoting flower pollination. Rapeseed grew well in 2003 under conditions of good rainfall. The lower yield of rapeseed in 2005 was attributed to scarce rainfall and high temperatures, especially in June when rapeseed was in its rapid growth phase.

Nutrient use efficiency can be expressed in many ways including partial factor productivity (PFP), agronomic efficiency (AE), and crop recovery efficiency (RE) (Fixen, 2007). This paper makes use of the latter two terms to assess the impact of balanced NPK application where AE refers to the crop yield increase per unit nutrient applied, and RE refers to the increase in plant nutrient uptake per unit nutrient added. Measurements of AE for applied N, P, and K resulted in large year-to-year variability which is likely linked to the over-riding climatic conditions in that particular year. Mean AE values were 5.4 kg/kg N, 5.8 kg/kg P_2O_5, and 3.2 kg/kg K_2O (**Table 5**). The respective ranges were 3.7 to 8.0 kg/kg N, 1.9 to 9.0 kg/kg P_2O_5, and 1.4 to 6.8 kg/kg K_2O. Plant nutrient uptake was much more consistent over years. Under the OPT treatment, each 100 kg rapeseed required 5.2 to 6.1 kg N (mean = 5.5), 0.8 to 2.8 kg P_2O_5 (mean = 1.7), and 4.1 to 5.1 kg K_2O (mean = 4.5). Nutrients taken up by plants are not only derived from applied fertilizer, but also from the soil native nutrient pool. The mean RE values were 33% for N, 13% for P, and 53% for K (**Table 5**). The respective RE ranges were 27 to 38% for N, 9 to 18% for P, and 40 to 60% for K.

Table 4. Effect of fertilizer application on rapeseed.

		Year				
		2002	2003	2004	2005	Mean[a]
Yield, t/ha	OPT	2.13a	2.59a	1.75a	1.48a	1.99a
	OPT-N	1.85b	2.29b	1.39b	1.24b	1.69c
	OPT-P	1.83b	2.48b	1.48ab	1.32b	1.78c
	OPT-K	2.07ab	2.51b	1.66ab	1.27b	1.88b
	Mean[b]	1.97b	2.47a	1.57c	1.33d	

[a] Different letters in the same column indicate significant difference between treatment at $p<0.05$.
[b] Different letters in the row indicate significant yearly difference at $p<0.05$.

Table 5. Nutrient use efficiency of N, P_2O_5, and K_2O.

		Year				
		2002	2003	2004	2005	Mean
Agronomic efficiency[a], kg/kg	N	4.4	3.7	8.0	5.3	5.4
	P_2O_5	6.8	1.9	9.0	5.4	5.8
	K_2O	1.5	1.4	2.9	6.8	3.2
Nutrient uptake/100kg seed[b]	N	5.5	5.3	5.2	6.1	5.5
	P_2O_5	1.6	1.6	0.8	2.8	1.7
	K_2O	4.6	4.1	4.1	5.1	4.5
Recovery efficiency[c], %	N	38	27	33	34	33
	P_2O_5	11	9	14	18	13
	K_2O	59	40	60	53	53

[a] Agronomic efficiency (kg/kg) = (yield of OPT - yield of omitted nutrient treatment)/ amount of nutrient applied)
[b] Nutrient uptake (kg/100 kg) = total of nutrient uptake (seed + straw)/seed yield x 100
[c] Recovery efficiency (%) = (nutrient uptake of OPT - nutrient uptake of omitted nutrient treatment)/amount of nutrient applied x 100

Mr. Yu Duan, Associate Professor, Inner Mongolia Academy of Agricultural and Animal Husbandry Science.

Summary

Results place a significant importance on balanced NPK management for optimal rainfed rapeseed production in IMAR. The importance of managing adequate nutrient supplies throughout the growing season is especially critical. Year-to-year climatic variability greatly influenced yield and nutrient use efficiency at the site. Although accumulative GDUs were reasonably consistent, precipitation throughout the entire year was constantly less than 400 mm and was much less during the growing season. Soil moisture limitations may be one reason why nutrient use efficiency values were relatively low. There will be great potential to increase rapeseed yield and nutrient use efficiency if current water limitations were removed by supplementing with irrigation in the future. BC

Mr. Duan is Associate Professor, Mr. Tuo is Professor, Mr. Zhao is Associate Professor, and Ms. Li is Assistant Professor. All work in Plant Nutrition and Analysis Institute, Inner Mongolia Academy of Agricultural and Animal Husbandry Sciences, China; e-mail: yduan@ppi.caas.ac.cn.

IPNI Project: Inner Mongolia-NMBF

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Nitrogen and Sulfur Fertilization for Improved Bread Wheat Quality in Humid Environments

By W.E. Thomason, C.A. Griffey, and S.B. Phillips

Bread wheat cultivars with high grain protein provide a higher value market for growers. However, limited knowledge of fertility management strategies exists for these types of cultivars for producers in the Mid-Atlantic region. We evaluated three bread wheat cultivars over nine site years in Virginia and found that application of 30 to 40 lb N/A between Zadoks growth stage (GS) 45 and 54 likely will result in consistent increases in grain protein concentration. Availability of S and a desirable N:S ratio in tissue is critical when considering the positive interaction between N and S on grain protein quantity and quality.

The wheat milling capacity in the Mid-Atlantic region of the U.S. is nearly 3.2 million tons of grain per year (World-grain.com, 2006). Most of this grain is purchased from other wheat growing areas, because relatively high grain protein levels are needed for good quality bread production and the soft red winter wheat (SRWW) cultivars grown in the Mid-Atlantic are typically lower in grain protein than the hard wheat grown in other regions. Because a higher value market exists for bread wheat, producers are seeking adapted cultivars and the agronomic techniques needed to grow good quality bread wheat in the humid, high rainfall Mid-Atlantic region.

The ability to increase grain protein concentration using late-season foliar N application has been demonstrated in bread wheat in other regions and has only recently been examined in more humid areas (Kratochvil et al., 2005). However, increased grain protein concentration does not always result in increased bread making quality because of the imbalance in N and S content as protein level increases.

The objectives of this study were to evaluate the effect of late-season foliar N and S applications on bread wheat yield and grain protein and to determine the optimum rate and timing for late-season N applications for bread wheat production in the humid Mid-Atlantic region.

Methods

Field experiments were conducted during the 2001 crop season in Virginia at Mt. Holly on a State fine sandy loam soil (Fine loamy, Typic Hapludult) and from 2002 to 2003 at Warsaw on a Kempsville loam (Fine-loamy, Typic Hapludult) and at Painter on a Bojac sandy loam soil (Coarse-loamy, Typic Hapludult). A split-plot design with eight replications was used to evaluate late-season N rates and timing. Sulfur, the main plot factor, was applied at a rate of 30 lb S/A to four of the eight replications at Zadoks GS 30 (Zadoks et al., 1974) in each year.

At Painter and Mt. Holly, treatments were applied only to the French bread wheat cultivar Soissons, a semi-hard wheat with moderate protein content. In the studies at Warsaw, two additional wheat cultivars…Heyne and Renwood 3260…were planted and evaluated along with Soissons. Heyne is a hard white winter wheat cultivar with high protein content and Renwood 3260 is a high protein, SRWW.

Spring N was split-applied to the entire test area at GS 25 (40 to 55 lb N/A) and again at GS 30 (45 to 75 lb N/A). Late-season foliar N treatments consisted of 0, 20, 30, and 40 lb N/A applied as dissolved urea solution at 45 gal/A at GS 37, GS 45, or GS 54. Plots were harvested with a small plot combine and grain sub-samples were analyzed for protein content.

Harvesting wheat plots in Virginia.

Results

Grain Yield Grain yields of all three cultivars varied from 59 to 130 bu/A over site years. However, a consistent relationship between late-season N application and grain yield was not observed. This lack of yield response to late-season N where N was not a yield-limiting factor is similar to that reported by Varga and Svecnjak (2006). Application of late-season N up to 40 lb N/A also did not decrease grain yield; thus, late-season N applications can be made to enhance grain protein concentration without a detrimental effect on yield.

Sulfur applied at 30 lb S/A at GS 30 had no effect on grain yield regardless of N treatment for any of the cultivars. Plant S levels at each site year were adequate, which may explain the lack of yield response. The ratio of N:S in plant tissue was generally not affected by S fertilization, which is similar to results reported by other researchers.

Grain Protein Averaged over years and locations, grain protein concentration of Soissons was not altered significantly with the addition of 30 lb S/A at GS 30 without late-season N. However, grain protein concentration increased an average of 0.2% when N was applied in conjunction with S (**Figure 1**). Based on the curvilinear response observed when both N and S were applied, a greater incremental advantage of S was

Abbreviations and notes for this article: N = nitrogen; S = sulfur.

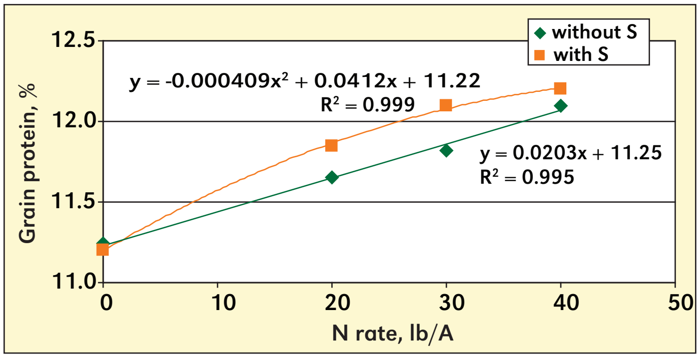

Figure 1. Mean grain protein response of Soissons wheat to late-season N with and without S applied at GS 30, at Mt. Holly, Warsaw, and Painter, Virginia, 2001-2003.

observed at lower N rates (20 and 30 lb/A). Late-season N alone increased grain protein concentration, but to a lesser extent than when the same N rate was applied to plots receiving S. This response agrees with the findings of Hocking (1994), who reported that remobilization of S from tissue to spring wheat grain was much lower than for N, indicating a continued need for S supply from outside the plant. Kratochvil et al. (2005) also reported that late season N (GS 37-50) was necessary to achieve the highest grain protein.

A significant linear increase in wheat protein concentration with increasing N rate was obtained in all site years (**Table 1**). This effect was also documented in prior studies with hard red winter wheat in the Mid-Atlantic region (Kratochvil et al., 2005). Averaged across site years, Soissons wheat protein concentration was 10.5, 11.1, 11.3, and 11.5% for the 0, 20, 30, and 40 lb N/A treatments, respectively (**Table 1**). Increases in grain protein concentration with application of 40 lb N/A versus the control treatment at Warsaw in 2002 and 2003 varied from 0.75 to 1.38% for Heyne, 0.83 to 0.85% for Soissons, and 0.43 to 0.70% for Renwood 3260. This variation indicates that the inherent genetic potential and composition of a given cultivar has a major impact on the magnitude and biological significance of the effects that a fertility management regime likely will have on grain, flour, and end-use quality characteristics. In five of nine comparisons, higher wheat protein concentrations were obtained with N application at GS 54 (**Table 1**).

Grain samples were analyzed for protein content.

Conclusions

Late-season foliar N applications up to 40 lb N/A did not result in consistent increases in wheat grain yield among the three cultivars, nor did they reduce grain yields of any cultivar. Similarly, application of 30 lb S/A at GS 30 did not affect grain yield of any cultivar. In contrast to yield, grain protein concentration of all three cultivars was consistently increased with late-season foliar N applications up to 30 to 40 lb N/A. Application of S to Soissons wheat in experiments conducted at Mt. Holly and Painter resulted in a significant increase in grain protein concentration when applied in conjunction with late-season N. Growth stage (45 versus 54) of late-season N application generally did not differ regarding the effect on grain protein, which affords producers a broader window of opportunity for late-season N applications.

In summary, application of 30 to 40 lb N/A between GS 45 and 54 to winter bread wheat cultivars grown in humid, high rainfall areas likely will result in consistent increases in grain protein concentration. Availability of S and a desirable N:S ratio in tissue is critical when considering the positive interaction between N and S on grain protein quantity and quality. BC

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Additional details on this study can be found in: Thomason, W.E., et al. 2007. Cereal Chem. 84(5):450-462.

Table 1. Wheat grain protein (%) following late-season foliar N applications.

	Mt. Holly 2002	Warsaw 2002	Warsaw 2003	Painter 2002	Painter 2003	Warsaw 2002	Warsaw 2003	Warsaw 2002	Warsaw 2003
	Soissons					Heyne		Renwood 3260	
N rate									
0	10.3	11.7	11.3	8.9	10.4	13.1	10.6	13.3	11.8
20	11.0	12.1	11.9	9.3	11.1	13.7	11.6	13.6	12.1
30	11.4	12.3	11.9	9.6	11.3	13.9	11.8	13.8	12.2
40	—	12.5	12.1	9.8	11.5	13.9	11.9	13.7	12.5
Growth stage[1]									
45	10.9	12.3	11.9	9.6	11.3	14.0	11.7	13.5	12.2
54	11.4	12.2	12.1	9.6	11.3	13.7	11.9	13.8	12.3
Contrasts									
N linear	*[2]	*	*	*	*	*	*	*	*
GS	*	*	*	ns[3]	ns	*	*	*	*

[1]Zadoks et al. (1974), [2]significant at p<0.05, [3]not significant.

Meeting the Phosphorus Requirement on Organic Farms

By Nathan Nelson and Robert Mikkelsen

Phosphorus management can be difficult in organic production since approved sources are limited and the consequences of under- or over-fertilization can be significant. Since P is an essential element for plant growth involved in many critical plant metabolic functions, sustainable agricultural production depends on an adequate P supply.

Nutrient management in organic production systems focuses on maintaining agricultural productivity with inputs of on-farm or minimally processed materials. Nutrient inputs for organic production are typically focused on carbon-based nutrient sources (e.g., crop residue, compost, manure) and nonprocessed mineral sources (e.g., rock phosphate, lime, and gypsum).

In most agricultural systems…both organic and conventional…complete nutrient cycling does not occur (**Figure 1**). The nutrient reservoir in the soil shrinks when crops are removed from the field at harvest. This nutrient export creates a P deficit, necessitating regular P additions to replace the harvested P. Several studies investigating whole-farm P budgets have found nutrient P deficits in many organic farms and illustrate the need for nutrient additions. Because P is an essential nutrient for plant growth, all sustainable systems should at a minimum seek to replace the P removed in harvested crops in order to avoid declines in yield and quality. Although organic agriculture seeks to minimize off-farm inputs, it is essential that producers replace P removed in harvested crops.

A brief review of the most commonly used P sources for organic production is presented here. More information and an extensive list of references are available at the website: **>www.ipni.net/organic/references<** .

Soil Organic Matter

Soil organic matter can be an important source of P for crops. Some studies have shown that soil organic matter increases on organically managed farms, while other long-term studies do not show such a buildup. These differences largely depend on management practices such as tillage intensity, heavy manure additions, return of crop residues, the extent of cover cropping, and climatic factors. Soil organic matter serves as a reservoir of plant nutrients, but may also improve the soil physical conditions and root environment.

A B

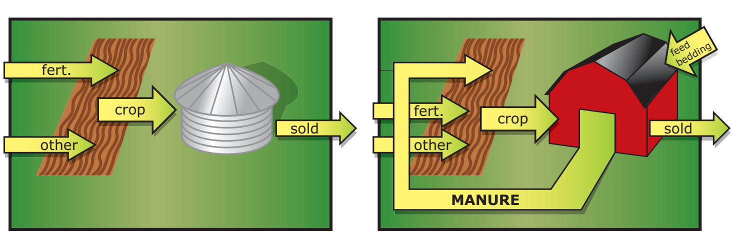

Figure 1. Nutrient inputs are required to maintain soil fertility on farms where crops are harvested and sold (A). On farms where crops and animals are both grown (B), nutrient management is more complex, but replacing harvested nutrients is still essential.

Soil organic matter contains a variety of organic P compounds, such as inositol phosphate, nucleic acid, and phospholipid (**Figure 2**). These compounds must be first converted to inorganic phosphate by soil enzymes before being used for plant growth. These phosphatase enzymes are produced by soil microorganisms, mycorrhizal fungi, or excreted by the plant root. Some organic P compounds are stable for many years in the soil, while others are converted to inorganic P within a few days or weeks.

Cover Crops

Cover crops are frequently grown in rotation with cash crops for a variety of beneficial purposes. The advantage of cover crops for P nutrition involves the accumulation of soil P by the cover crop. This P is subsequently released when the cover crop is killed. Numerous studies have shown that some cover crops can provide a P nutritional benefit for the next crop compared to crops grown without a preceding cover crop. This is attributed to the ability of some species to draw down soil P concentrations below what some cash crops can and also to their extensive root system. This P drawdown may also be the result of root exudates and the efficient P uptake by the cover crop roots. Some cover crops can be excellent hosts for mycorrhizal fungi, which may allow a greater exploitation of the soil P reserves.

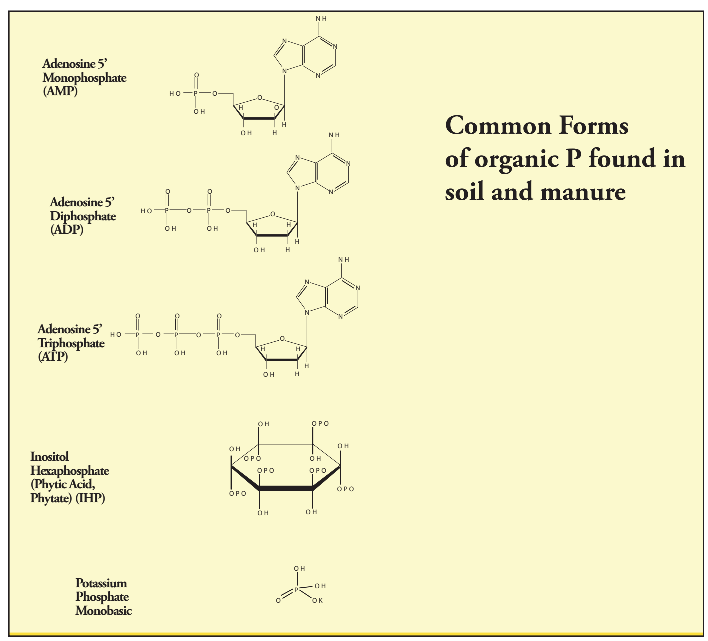

Figure 2. Common forms of organic compounds found in soil and manure compared with inorganic phosphate.

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

Cover crops can improve soil properties, reduce erosion, and increase the nutrient supply to the following crop.

There are considerable differences in the ability of various cover crops to provide additional P for the subsequent crop. Research has generally shown a greater P benefit from legume cover crops than from grass cover crops, but the effects of cover crops on P nutrition can be highly variable. In many cases, supplemental P is still required after the cover crop to eliminate P deficiency. In some circumstances, P uptake by the cash crop following the cover crop is actually reduced due to low residual soil P caused by uptake by the cover crop and poorly synchronized P release.

Cover crops offer some P nutritional benefits in some circumstances. The variable results (positive and negative responses) are due to the complicated species, microbial, and environmental interactions that are not easy to predict. However, it must be remembered that cover crops do not provide any new P to the soil, but only allow the existing soil P reserve to be used more efficiently. With removal of P from the field in harvested products, the nutrient supply must be ultimately replaced with an additional supply to maintain sustainability.

Mycorrhizal Fungi

Enhanced P uptake is frequently cited as a primary benefit of mycorrhizal fungi colonization. In this symbiotic relationship, the plant root provides the energy (carbohydrate) for the fungi in exchange for improved nutrient uptake and other plant root benefits. Almost all crop plants form this relationship with mycorrhizal fungi, which is present in the root zone of most soils. **Figure 3** shows mycorrhizal association with roots.

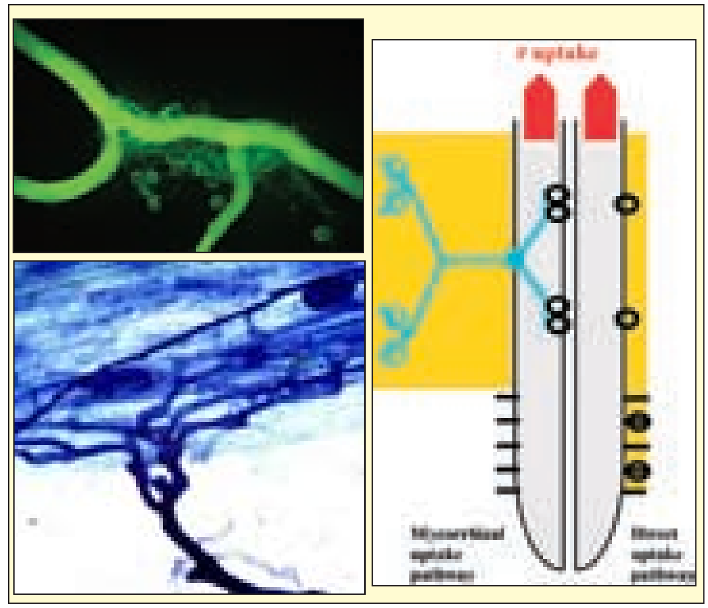

Figure 3. Mycorrhizal fungi play an important role in providing P for 80% of global plant species. Hyphal strands of fungi extend from 1 to 15 cm into the soil, scavenging the soil for immobile nutrients such as P.

Many organic growers encourage the associations of mycorrhizal fungi with crop roots through the use of cover crops and rotations. However, frequent tillage commonly used for weed control causes a disruption of the soil fungal network and may reduce its effectiveness for providing nutrients to the plant.

The value of mycorrhizal fungi for supplying P for crops is most apparent in low-P soils. In most cases, plants growing in soils with medium to high concentrations of P have less mycorrhizal association than plants in low-P conditions. Therefore, the value of mycorrhizal fungi is greatest in soils without an adequate supply of P. Similar to cover crops, mycorrhizal fungi do not provide any additional P to the soil, but can allow better utilization of the existing soil resource. Commercial sources of mycorrhizal fungi are available and may be used in specialized conditions.

Rock Phosphate

Rock phosphate.

Rock phosphate (apatite) is a general term used to describe a variety of globally distributed P-rich minerals. Of the two main types (sedimentary or igneous), sedimentary rock deposits are the source of over 80% of the total world production of phosphate rock. Depending on its geologic origin, rock phosphate has widely varying mineralogy, texture, and chemical properties. Some rock P is found in hard-rock deposits, while other rock P is found as soft colloidal (soil-like) material. This great variation in properties and the accompanying elements present in the rock (such as carbonate and fluoride) has a large effect on its value as a source of plant nutrient. This range in properties makes some rock P sources excellent nutrient sources and other sources quite unsuitable. Unfortunately, the information on P availability from a specific rock source is not generally available to the consumer.

The general reaction of rock P dissolution added to soils to a plant available form is:

Equation 1: $Ca_5(PO_4)_3F + 6H^+ \leftrightarrow 5Ca^{2+} + 3H_2PO_4^- + F^-$

Note the importance of acidity (H^+) and low Ca^{2+} in this reaction.

It is difficult to make universally applicable recommendations for rock P application because so many factors affect its dissolution and plant availability. However, the key factors to consider include:

- Soil pH is important in the dissolution of the rock P (Equation 1). Rock P is much more soluble in acidic soils (soil pH <5.5). In neutral pH to alkaline soils, rock P typically provides little benefit for plant nutrition, except under special conditions.
- Particle size influences the dissolution of rock P by controlling the surface area available for reaction. However, fine grinding a low-reactivity phosphate rock will not significantly increase P availability due to its insoluble mineralogical structure. Conversely, it may not be necessary to finely grind highly reactive rocks used for direct application to the soil. Many rock P sources are commonly ground to <100 mesh (0.15 mm) to improve reactivity, but such finely ground material may be difficult to handle and to spread uniformly.
- Low soil Ca concentrations and high soil cation exchange capacity favor rock P dissolution since Ca is one of the reaction products resulting from dissolution. Soil conditions that limit Ca availability (soil acidity, high leaching, or the presence of organic compounds that complex exchangeable Ca) also tend to favor rock P dissolution and the release of P for the plant.
- Other cultural practices that may improve P availability from rock P include broadcast applications to maximize soil dissolution reactions, and using management that promotes root colonization by mycorrhizal fungi. Application of rock P should be made several weeks or months prior to the anticipated need for plant nutrients. Although lime applications are important for reducing harmful effects associated with soil acidity, lime additions tend to reduce the value of rock P as a nutrient source.

Manure and Composts

These materials are generally excellent sources of P for plants. Even though these materials are considered as organic products, over 75% of the total P they contain is present as inorganic compounds. It is commonly recommended that the P in manure and compost be considered as 70% available for soils with low soil-test P, but 100% available for soils testing adequate or high for P.

The ratio of nutrients in composts and manures does not closely match that required by plants nor in the harvested products. When manure and compost are used as a primary N source for crops, P is typically overapplied by 3 to 5 times compared with the crop removal rate. Long-term use of manures and compost as the primary N source leads to an accumulation of P in the soil that can become an environmental concern for surface water quality.

Ground bone meal

Bone Meal

Bone meal, prepared by grinding animal bones, is one of the earliest P sources used in agriculture. Most commercially available bone meal is "steamed" to remove any raw animal tissue. The primary P mineral in bone material is "calcium-deficient hydroxyapatite" [Ca_{10}–x(HPO_4)x(PO_4)6–x $(OH)_2$–x (0 < x < 1)], which is more soluble than rock phosphate, but much less soluble than conventional P fertilizers. Calcium-deficient hydroxyapatite present in bone meal dissolves:

Equation 2: $Ca_{9.5}(HPO_4)_{0.5}(PO_4)_{5.5}(OH)_{1.5} + 13H^+ \leftrightarrow 9.5Ca^{2+} + 6H_2PO_4^- + 1.5H_2O$

Similar to rock P, bone meal is most effective in acidic soils and when the particle size is small. When used properly, it can be an effective P source. One of the first commercial P fertilizers was produced by reacting animal bones with sulfuric acid to enhance the solubility of P.

Concerns have been raised regarding bovine spongiform encephalopathy (BSE) in cattle and the residual effect of bone meal as a fertilizer. There are no restrictions on the use of bone meal and most commercial bone meal products have been heat treated, so the potential for prion transmission is small.

Guano

Guano is most commonly used as a source of N for plants, but some guano materials are also relatively enriched in P. Guano is mined from aged deposits of bird or bat excrement in low rainfall environments. The drying and aging process changes the chemistry of the P compared with fresh manure. Struvite (magnesium ammonium phosphate) can be a major P mineral found in guano, dissolving slowly in soil. The limited supply and high cost of guano generally restricts its use to small-scale applications.

Summary

There are several options available for meeting the P requirement for organic production. Growers are encouraged to first consider locally available materials to meet this need. Many of the allowed materials are fairly low in nutrient content, therefore transportation costs may be a concern since relatively large quantities of amendment may be needed to meet the crop demand. Regular soil and tissue testing should be conducted by all growers to avoid depletion of soil nutrients and to prevent inadvertent nutrient accumulation, regardless of production philosophy and management techniques. BC

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Nutrient Deficiency Photo Contest Results Announced by IPNI

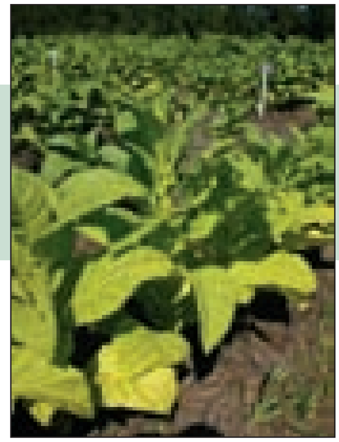
Congratulations to the winners of the 2007 photo contest and sincere thanks to those who submitted entries. On this page, we highlight winners for each of the four categories. The entries were judged on the overall quality of the image as well as the supporting data provided by entrants. All entries are posted for viewing on the IPNI website at: **>www.ipni.net/2007photocontest<**.

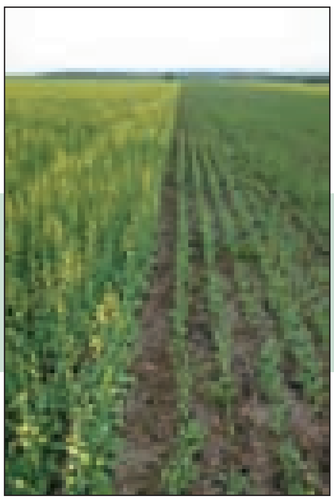
We encourage readers to look for opportunities to capture digital photos and document crop nutrient deficiencies and disorders in 2008. Also watch for details outlining the 2008 edition of the IPNI contest in the next issue of *Better Crops with Plant Food* and at the website.

Nitrogen Category…N-Deficient Tobacco

Adriana Elina Ortega of Salta, Argentina, took this shot showing N deficiency in tobacco under no-till cultivation and mulch. Plants had a light green appearance and a definite yellowing of older leaves. Fully developed leaves had 1.79% N total and cured leaves had 1.18% N total.

(Second place: S. Srinivasan, Tamil Nadu, India. Third place: Ryan Stoffregen, Illinois, U.S.A.)





Phosphorus Category…P-Deficient Canola

Lyle Cowell of Saskatchewan, Canada, noticed this unintended 'test strip' in a canola crop that was direct-seeded into alfalfa stubble. The previous alfalfa crop depleted soil P and, in this case, the farmer ran out of seed-row P fertilizer on the last pass during seeding, causing slow and stunted growth.

(Second place: Nathan Slaton, Arkansas, U.S.A. Third place: Mr. Syafruddin, South Sulawesi, Indonesia.)

Potassium Category…K-Deficient Bermudagrass

Colin Massey of Arkansas, U.S.A., captured this image of K deficiency in bermudagrass. The crop received no K over a 2-year period. Mean soil test K in 2007 was 82 ppm. Tissue K concentration in 2007 ranged from 0.57% to 1.03% across four harvests. Averaged across harvests, total biomass with no K fertilizer was 59% of yields produced with 560 kg K_2O/ha applied over the four harvests.

(Second place: Li Yuying, Heilongjiang, China. Third place, Nathan Slaton, Arkansas, U.S.A.)

Other Category…B Deficiency in Coconut Palm

P. Jeyakumar of Tamil Nadu, India, took this close-up photo showing B deficiency in a 14-year-old coconut palm. The deficiency was confirmed with symptoms such as early shedding of buttons (female flowers), resulting in poor fruit set, plus small and unevenly opened leaves. The developed nuts were also small and malformed. The soil test revealed that B content was very low (less than 0.3 mg/kg). Leaf tissue analysis also registered a lower value of 14 mg/kg.

(Second place: Luis Estrada, Guatemala. Third place: Nolver Arias, Santander, Colombia.)

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; B = boron; ppm = parts per million.

Cash prizes are awarded in each of the four categories as follows: First place: US$150.00; Second place: US$75.00; Third place: US$50.00. BC

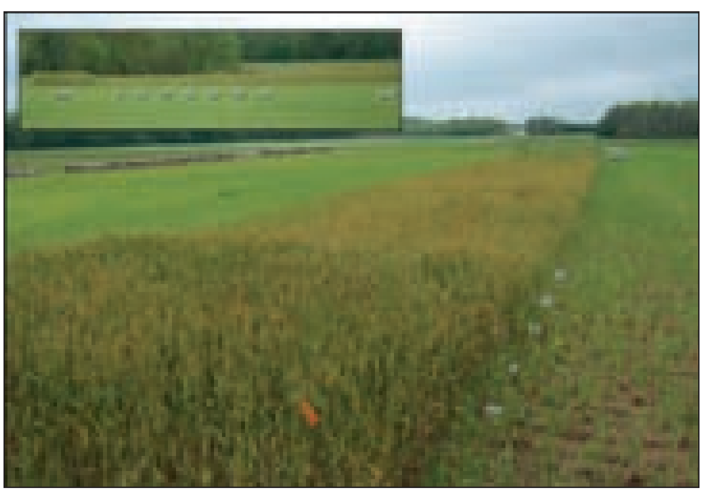
Determining Mid-Season Nitrogen Rates with Ramp Calibration Strip Technology

By D.E. Edmonds, M.C. Daft, W.R. Raun, J.B. Solie, and R.K. Taylor

Methodologies currently available for making mid-season fertilizer N recommendations in most crops are not consistent from one region to the next. The use of chlorophyll meters, economic optimums, optical sensor-based yield prediction models, preplant soil testing, and yield goals have all, to some extent, been limited regionally. The methodology discussed in this article is a simple approach for applying preplant N fertilizer in automated gradients used for determining mid-season N rates based on plant response.

The need to improve N use efficiency (NUE) both in large and small scale operations has become increasingly acute with increased fertilizer N prices and added scrutiny associated with potential adverse affects on our environment from N loss. Similar to that encountered in other regions of the world, Lobell et al., 2004 showed that for wheat farmers in Ciudad Obregon, Mexico, N fertilizer represented the single largest cost of production. They further noted that anything that can be done to match N supply to spatial and temporal variations in crop demand could assist in achieving greater crop yields and improved agricultural sustainability. While seemingly straightforward, Pang and Letey (2000) also noted the difficulty in matching the time of mineral N availability with N uptake in crop production. The ramped calibration strip (RCS) provides a mid-season visual estimation of additional fertilizer N needed, while accounting for N mineralized from planting to time of inspection.

The RCS is based on the concept of visually evaluating plots with incremental rates of preplant N to identify the minimum N rate required for maximum forage production. The lowest preplant N rate that results in maximum midseason forage production (determined visibly or using an active hand-held NDVI sensor) provides an estimate of additional N needed to achieve optimum grain yield. Assuming that maximum or near maximum yields can be achieved from mid-season applied N, producers can evaluate the RCS in-season to determine the optimum rate, prior to applying additional N. The maximum desired application rate where a fertilizer response can be obtained can be estimated visually or calculated from measurements of NDVI. Farmers can observe the point where crop growth reaches a plateau. They can then calculate an N rate by dividing the distance from the start of the 0-N rate to that point by the total ramp length multiplied by the maximum application rate.



Wheat N-ramp at Stillwater, Oklahoma. High N rate (196 lb/A) in the foreground followed by 0 N rate, ramping back up to the high N rate in the background.

Wheat N-ramps at Stillwater, Oklahoma. High N rate (196 lb/A) in the foreground followed by 0 N rate, ramping back up to the high N rate in the background.

The concept of using the RCS to determine the optimum wheat topdress N rate is illustrated in **Figure 1**. By stopping at the point (recording distance in m) where there are no longer visible changes in plant growth or differences in NDVI as measured by the sensor (secondary vertical axis), you can plot or mentally visualize a linear-plateau function. The point where the transition curve reaches the plateau is the recommended topdress N rate. For the field in **Figure 1**, the recommended topdress N rate would have been around 104 lb N/A (140 kg N/ha). This is because the RCS was applied on-top of the farmer practice (whatever that may be) and the point where vegetative growth was maximized beyond that seen for the farmer practice would be the peak in the NDVI curve, and that was associated with the corresponding 104 lb N/A rate. Assuming that we can "catch up" and/or achieve maximum yields from the mid-season N application, and assuming that yield potentials were not severely restricted by early season N stress, the RCS interpolated rate is the application rate needed

Abbreviations and notes for this article: N = nitrogen; NDVI = normalized difference vegetation index.

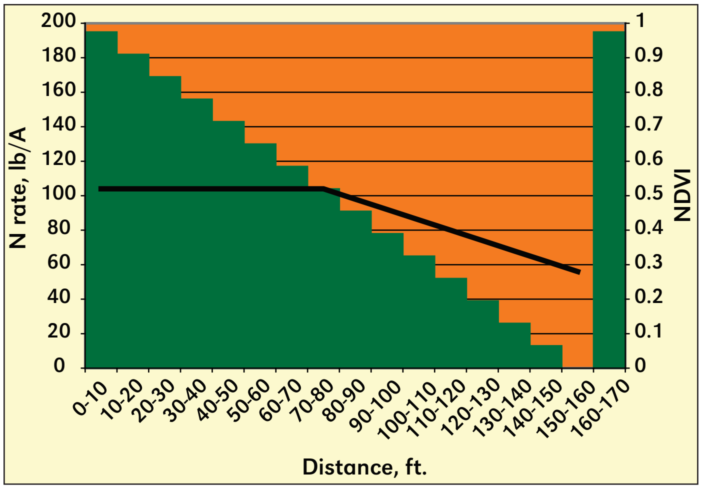


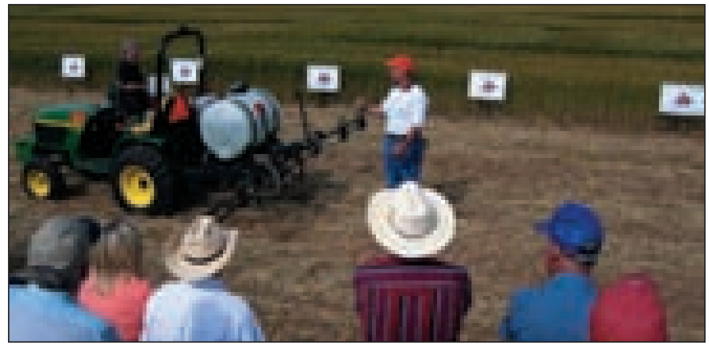
Figure 1. Fertilizer N applied and NDVI over distance traveled. Mid-season fertilizer N application is determined by finding the point where NDVI was maximized, then move horizontally to the desired N rate. In this wheat example from the EFAW Research Experiment Station located in Stillwater, Oklahoma, the optimal N rate in the spring of 2007 was 104 lb/A.

on the rest of the field to achieve the same "visible" or NDVI recorded response. In practice, farmers adjust mid-season N rates based on their experience. However, the RCS application rate provides them with a reasonable maximum target that accounts for temporal variability.

RCS constitutes one observation within a field; therefore, recommended practice calls for establishing more than one RCS per field. Earlier experience with the N Rich Strip (Mullen et al., 2003) showed that measurements of the area with the greatest response to additional N should be used to calculate the topdress N application rate. Similarly, we recommend that the RCS with the greatest response should be used to estimate topdress N application rate. In general, if in-season N is applied at or before V8 and Feekes 5 for corn and wheat, respectively, early season N stress will not result in lost yield potential.

Data from multiple-year corn and wheat experiments documents that in some years zero N check plots can produce near maximum yields (Olson et al., 1986; Bundy, 2003; Bundy, 2006; Johnson and Raun, 2003; Meisinger et al., 1985; Olson, 1980). For cited examples where check plots (0-N) produced near maximum yields, an RCS would have likely visibly illustrated limited differences between the zero N segment and plots in the RCS receiving N. As a result, in-season observation would have recognized limited or no demand for additional N fertilizer.

If check plots with no fertilizer N looked as good as the fertilized plots, where was N coming from? Over the years, we have observed that warm wet winters (winter wheat) and warm wet springs and early summers (corn) are conducive to increasing the amount of N mineralized from soil organic matter and N deposition in rainfall. There are years where the demand for fertilizer N is limited (and highly dependent on the environment), and other years when it is cool and dry and the demand for fertilizer N is greater. Midseason evaluation of the RCS provides an estimate of how much N the environment delivered.



Dr. Randy Taylor, OSU Extension, educates producers on the importance of N-ramp technology. OSU's ramp applicator is also shown in front of wheat N-ramps in Lahoma.

For producers interested in using active NDVI sensors for determining midseason N rates, they can mark the start and end of the RCS (preplant or soon after planting), and collect sensor data using handheld NDVI sensors walking at a constant speed over the length of the ramp. Producers can measure NDVI with the GreenSeeker™ sensor over the entire RCS, then using the Ramp Analyzer 1.12 program (available on the downloads page at www.nue.okstate.edu), read the sensor data file, and the optimum N rate will be computed accordingly (identifies where NDVI peaks within the RCS). Sensors are recommended simply because our eyes are not as sensitive in picking up differences; however, walking the RCS is a viable method of visually inspecting N response.

A number of individuals and companies are interested in building variants of the RCS applicator. Instructions for constructing the Oklahoma State University version of the RCS applicator are available on our website: www.nue.okstate.edu.

Information on several farmer built RCS applicator designs, and names and addresses of companies building the RCS applicators are also included on this site: www.nue.okstate.edu/Index_RI.htm.

Ultimately, applied methodologies that integrate farmer intuition and farmer input within the decision making process could assist in increasing adoption. While the RCS approach may be limited in deciphering exact maximum N rates in high yielding environments, it provides a visual mid-season alternative for N fertilization, in opposition to applying all N preplant in crop production systems that are known to be inefficient. BC

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Balancing Fertilizer Use and Profit in Asia's Irrigated Rice Systems

By R.J. Buresh and C. Witt

About 90% of Asia's population, particularly the most impoverished, depend on rice as a source of their calories. The production of sufficient rice in Asia at an affordable price for the poor relies on the effective use of fertilizers, especially in the irrigated lowlands that produce 75% of Asia's rice.

Increasing fuel and fertilizer prices raise concern about whether Asian rice farming can successfully maintain the delicate balance between sufficient profitability for farmers and sufficient rice supply at affordable prices for the urban and the non-farming rural poor. Rising prices for fertilizers could stimulate rice farmers and policy makers to examine existing use of fertilizer. Reductions in fertilizer use and adjustment in the relative use of fertilizer N, P, and K might appeal to farmers and policy makers as fertilizer prices increase. But, crop yield is directly related to amount of nutrient taken up by a crop. At some point, less fertilizer use means lower crop yield and less profit for farmers. How much fertilizer use is just right for high profit?

In this paper we provide principles that address critical agronomic and economic issues at the farm level as fertilizer prices increase. We aim for principles that assist farmers in decision making on nutrient and crop management to achieve high productivity and profitability at low risk while meeting acceptable standards of environmental quality.

Topdressing N fertilizer to rice. (Photo courtesy of IRRI).

Ensuring Profitable Fertilizer Use — N

Nitrogen is typically the nutrient most limiting rice yield and the nutrient needed in largest quantity from fertilizer. In Asia's irrigated rice systems, the naturally occurring (i.e., indigenous) supply of N from soil is typically sufficient to achieve a grain yield of 3 to 5 t/ha without application of fertilizer N (Dobermann et al., 2003), and even higher yields of 5 to 7 t/ha without fertilizer N can be achieved in irrigated areas of China (Peng et al., 2006). But across Asia, yields of irrigated rice in the absence of fertilizer N are consistently insufficient to meet food needs and achieve highest profit for farmers. Fertilizer N is clearly needed, but the optimal management of fertilizer N to match crop needs and achieve high profit is season and location specific, varying even among adjacent fields within the same season.

We present four scenarios to illustrate principles for ensuring profitable rice farming as the price of fertilizer N increases. The four scenarios increase progressively in intensity of required knowledge and in magnitude of potential benefits to rice farmers. In all scenarios we use the production function illustrated in **Figure 1a** to represent an existing situation in a farmer's field, and we use the following to assess the effect of a 50% increase in cost of fertilizer N:

- Farm gate price of unmilled (paddy) rice = US$0.31/kg
- Cost of fertilizer N: Standard = US$0.59/kg, the current non-subsidized price in Indonesia. Cost with 50% increase = US$0.87/kg

The increase in grain yield with incremental addition of fertilizer N is location and season specific, depending upon many factors including rice variety, climate, crop management, management and timing of fertilizer N, use of organic inputs, and the sufficiency of other essential nutrients. We, therefore, selected a generic response of rice to fertilizer N (**Figure 1a**). The grain yield of 3.5 t/ha without fertilizer N is near the average for irrigated areas outside China without input of manure (Dobermann et al., 2003). The maximum yield of 5.6 t/ha and the maximum increase in yield of 2.1 t/ha with fertilizer N reflect a response of intermediate magnitude for irrigated rice in Asia.

The increase in yield per unit of applied fertilizer N (i.e., agronomic efficiency of fertilizer N, AE_N) is a measure of the efficiency of fertilizer N use by the crop. The AE_N decreases with increasing fertilizer N (**Figure 1a**).

The gross return over fertilizer cost (GRF), which is the farm gate revenue from produced rice minus cost for fertilizer N applied, provides a relative measure among scenarios for the benefit derived by farmers from the use of fertilizer N. The GRF is largest at the point of profit maximization in the production function, which occurs at a fertilizer N rate slightly less than the maximum yield. In **Figure 1a**, profit maximization with standard fertilizer N cost occurs with use of 138 kg N/ha to achieve a yield of 5.6 t/ha with AE_N = 15 kg/kg (**Table 1**). An AE_N near 15 kg increase in grain per kg N applied is common with existing management practices for irrigated rice in Asia. Although markedly lower AE_N (<10 kg/kg) is widespread in China as a result of high fertilizer N use relative to the increase in yield from N fertilization (Peng et al., 2006).

Fertilizer represents only a fraction of total input costs in rice farming. In a 1999 study across seven irrigated rice areas of Asia, fertilizer represented from 11 to 28% of total input

Abbreviations and notes for this article: N = nitrogen; P = phosphorus; K = potassium; Zn = zinc; IRRI = International Rice Research Institute.

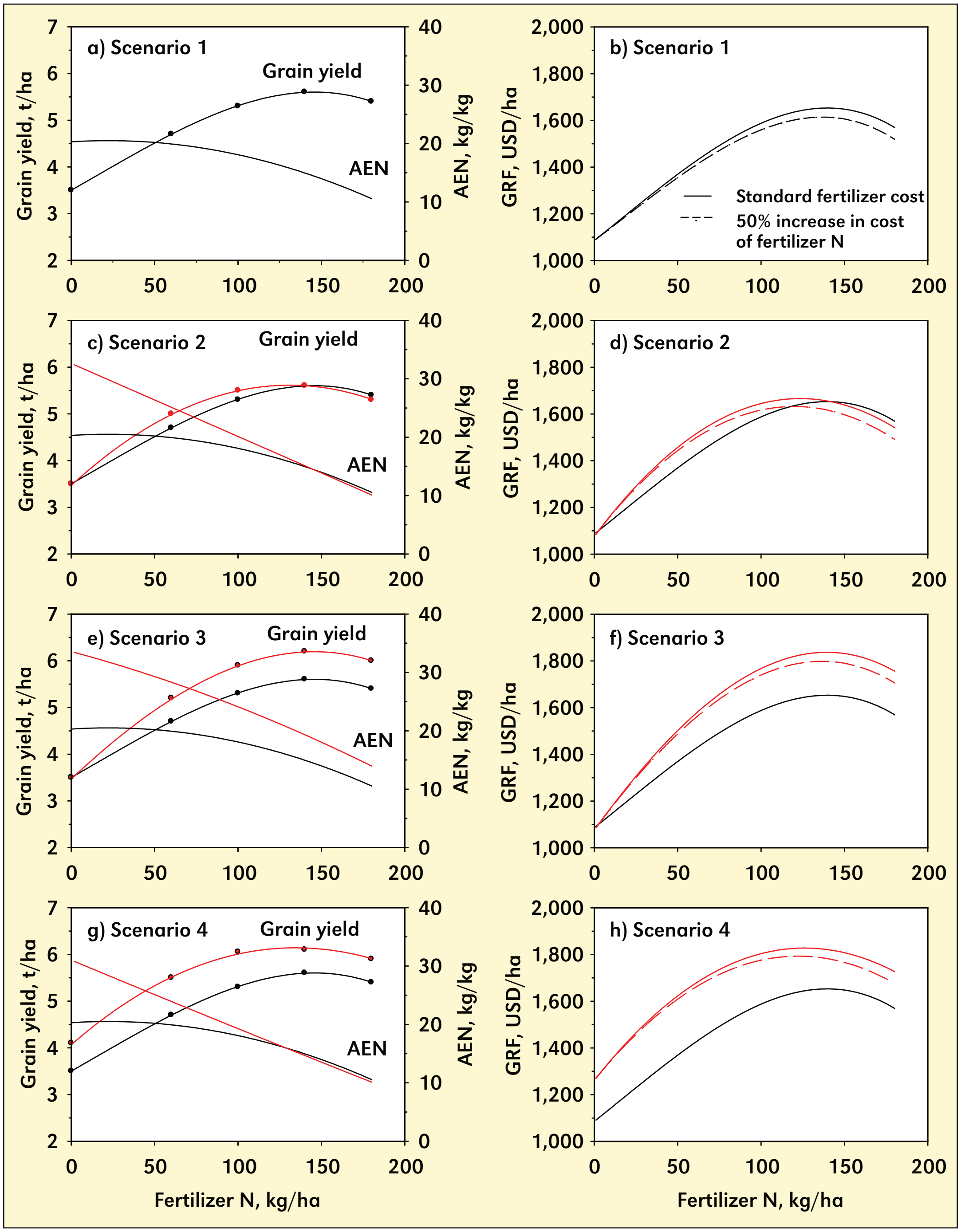

Figure 1. Example for a typical production function in a farmer field (a) and gross return over fertilizer cost (GRF, revenue minus cost for fertilizer N applied) for two fertilizer N costs (b). The red lines for production functions in (c), (e), and (g) represent different scenarios for changes in management (see text for further information), while the black line represents the function in farmer field (a). Figures (d), (f), and (h) represent the GRF for the respective scenarios, at two fertilizer N costs, relative to the typical production function at standard fertilizer N cost in (b). AE_N = agronomic efficiency of fertilizer N.

cost (Moya et al., 2004), and fertilizer N would represent only a portion of this total fertilizer cost. The net benefit of rice farming would be markedly less than GRF because GRF does not consider costs other than fertilizer N; but GRF provides a valuable measure of the relative differences in benefits between reported scenarios and fertilizer N costs. In our analysis, we assume that labor requirements and input costs other than for fertilizer N do not alter with the changes in fertilizer and crop management required to achieve the production functions for Scenarios 2 to 4.

Scenario 1: Improving the pre-season estimate of required fertilizer N

In some areas of Asia the profitability of rice farming, even at existing fertilizer N prices, can be increased by simply adjusting the rate of fertilizer N with no other change in the existing management practices for fertilizer N and rice. Rice farmers and extension workers often underestimate indigenous N supply and the yield without fertilizer N (Y_0) in irrigated rice fields. The flooding of soils for production of rice enhances indigenous N supply and Y_0 through greater inputs of N via biological N_2 fixation and greater net release of plant-available soil N. An underestimation of Y_0 translates into an overestimation of crop response to fertilizer N (ΔY) and the requirement for fertilizer N. The ΔY in irrigated rice fields in Asia is often in the range of 1 to 2 t/ha. In favorable high-yielding seasons, ΔY can increase to 3 to 4 t/ha. In China despite relatively high yields of fertilized rice, ΔY is typically ≤2 t/ha and only periodically 3 t/ha (Peng et al., 2006; Wang et al., 2007).

The site-specific nutrient management (SSNM) as developed for rice in Asia (Dobermann et al., 2004; IRRI, 2007) can be used to quickly assess whether existing fertilizer N rates can be reduced to increase profit. The first step is to estimate through best available information whether the anticipated response of rice to fertilizer N with existing crop management practices (ΔY) approximates 1, 2, 3, or 4 t/ha. If farmers currently use >80 kg fertilizer N per each ton of increased paddy yield from fertilizer N (AE_N<12 kg/kg), then the fertilizer N rate can likely be decreased with no loss in yield.

Farmers should ideally fertilize to achieve the yield where GRF is maximum—the point of profit maximization. In the case of the production function illustrated in **Figure 1a**, the yield

Table 1. Yield, fertilizer N, and fertilizer N efficiencies at two fertilizer N costs for scenarios 1, 2, 3, and 4 of Figure 1 as described in the text. GRF = Gross return over fertilizer cost

Parameter		Unit	Scenario 1	2	3	4
Grain yield, without N	Y_0	t/ha	3.5	3.5	3.5	4.1
Grain yield, maximum	Y_M	t/ha	5.6	5.6	6.2	6.1
N rate, at Y_M	N_M	kg/ha	145	129	144	132
Standard fertilizer N cost						
Grain yield, at maximum GRF	Y	t/ha	5.6	5.6	6.2	6.1
Fertilizer N, at maximum GRF	F_N	kg/ha	138	120	136	122
Agronomic efficiency of N, at maximum GRF	AE_N	kg/kg	15	17	20	17
Change in net benefit at maximum GRF in scenarios 2, 3, and 4 relative to scenario 1	ΔGRF	US$/ha	–	+10	+180	+170
50% increase in fertilizer N cost						
Grain yield, at maximum GRF	Y	t/ha	5.6	5.6	6.2	6.1
Fertilizer N, at maximum GRF	F_N	kg/ha	133	114	132	116
Agronomic efficiency of N, at maximum GRF	AE_N	kg/kg	16	18	20	17
Change in net benefit at maximum GRF in scenarios 1, 2, 3, and 4 at increased fertilizer cost compared to farmers' practice (scenario 1) at current fertilizer price	ΔGRF_{50}	US$/ha	-40	-20	+140	+140

at maximum GRF is 5.6 t/ha, and ΔY fits into the category of 2 t/ha (5.6 – 3.5 t/ha). An estimated requirement for fertilizer N based AE_N=15 kg/kg, which is often achievable with farmers' crop and fertilizer N management, would be 130 kg N/ha (2 t/ha x 1000/15). The use of more than 160 kg N/ha (AE_N<12 kg/kg) in such a location would be a clear warning of excessive fertilizer N use.

An increase in fertilizer N cost with no change in the production function, other costs, and farm gate paddy price would decrease profit (**Figure 1b**). With 50% increase in fertilizer N cost, the N rate at maximum profit decreased slightly from 138 to 133 kg N/ha (**Table 1**). Net benefit decreased by 40 US$/ha with the increase in fertilizer N cost.

When current rates of fertilizer N are excessive, an optimization of fertilizer N use can compensate for increased fertilizer N cost. For example, if current fertilizer N use is 170 kg N/ha, a reduction to the optimal of 133 kg N/ha would match additional cost for a 50% increase in fertilizer N and avoid a loss in profit. But if current fertilizer N use was <165 kg N/ha, the cost savings from a reduction of fertilizer N use would not by itself negate the 50% rise in fertilizer N cost. In such case, a shift in the production function through improved management practices would be required to negate the additional cost of fertilizer N.

Scenario 2: Reducing fertilizer N use through improved management

Asian rice farmers typically do not manage fertilizer N most effectively. For example, the early application of fertilizer N within 2 weeks after rice establishment often exceeds crop needs leading to excess vegetative growth and increased susceptibility to diseases and some insect pests (Peng et al., 2006; Wang et al., 2007). For best effect, farmers should apply fertilizer N several times during the growing season to ensure that the N supply matches the crop need for N at the critical growth stages of active tillering and panicle initiation. The SSNM approach provides principles for effective N management, including use of the leaf color chart (LCC) to assess leaf N status and adjust fertilizer N applications to match the needs of the rice crop for N (IRRI, 2007, Witt et al., 2007).

An improvement in fertilizer N management can shift the production function to the left toward greater efficiency of N use as illustrated in **Figure 1c**. In this case the primary focus is reducing fertilizer N use to increase profit. This represents situations where existing fertilizer N use, even when greater than optimal, has resulted in yield that cannot be increased further solely by improvements in N management.

"Reduce fertilizer N to increase profit" can at first glance seem an appealing message for farmers. Opportunities typically exist for farmers to further improve the distribution of fertilizer N to better match the crop needs for supplemental N. But farmers using fertilizer N near or above the rate for maximum GRF, derive little or no benefit from a savings in fertilizer N through improved N management without an accompanying increase in yield at maximum GRF (**Figure 1d**). Net benefit with Scenario 2 was only US$10/ha at the standard fertilizer N cost (**Table 1**).

When fertilizer N cost was 50% higher, the fertilizer N rate at maximum GRF decreased from 133 kg/ha in Scenario 1 to 114 kg/ha in Scenario 2 (**Table 1**). The savings in fertilizer N associated with Scenario 2, however, failed to compensate for the added costs associated with the 50% increase in fertilizer N cost (**Figure 1d**). There was a net loss of US$20/ha relative to the typical production function (Scenario 1) at standard fertilizer N cost.

The AE_N at maximum GRF in Scenario 2 was 17 kg/kg at standard fertilizer cost and 18 kg/kg with increased fertilizer N cost (**Table 1**). Based on research across Asia, an AE_N of 18 kg/kg in low-yielding seasons and 20 kg/kg or more in high-yielding seasons can be achieved with good N management including within season N adjustments using the LCC.

The greatest benefit from improved N management through a shift in the production function (Scenario 2) occurs for farmers using suboptimal rates of fertilizer N. Grain yields in Scenario 2 are markedly greater than grain yields for the typical production function at suboptimal N rates from 30 to 90 kg N/ha (**Figure 1c**). This translates into markedly higher GRF, and correspondingly higher net benefit, for Scenario 2 regardless of fertilizer N cost (**Figure 1d**).

With Scenario 2, farmers using suboptimal rates of fertilizer N could increase profit by increasing fertilizer N use despite a 50% increase in fertilizer N cost. For example, increasing N rate from 80 kg N/ha with existing management practices to the rate at maximum GRF (114 kg N/ha) with improved N management in Scenario 2 would increase net benefit by

Leaf color chart can be used to assess leaf N status and help adjust fertilizer applications. (Photo courtesy of IRRI.)

US$110/ha when fertilizer N cost increased by 50%. However, such suboptimal fertilizer N use is markedly less common for irrigated Asian rice farmers than the use of fertilizer N near or above the rate for maximum GRF.

Scenario 3: Increasing yield through improved management

An improvement in fertilizer N management can in some cases increase the maximum attainable yield, resulting in an upward shift in the production function as illustrated in **Figure 1e**; but an appreciable upward shift of the production function is most likely when improved fertilizer N management is accompanied by improved management to alleviate a major yield-limiting constraint such as insufficient supply of other nutrients (Alam et al., 2006). In this case, the primary focus is on overcoming yield-limiting constraints in order to increase profit through higher production rather than through an adjustment in input use per se. This scenario is most feasible where yield is constrained by a readily identifiable and easily alleviated limitation.

Scenario 3 illustrates an upward shift in the production function of 0.6 t/ha to 6.2 t/ha at maximum GRF (**Figure 1e, Table 1**). This substantially increases GRF relative to the typical production function in Scenario 1 (**Figure 1f**). The net benefit at maximum GRF was US$180/ha with standard fertilizer N cost (**Table 1**).

When fertilizer N cost was 50% higher, GRF remained higher with Scenario 3 than the typical production function with standard fertilizer N cost (**Figure 1f**). Scenario 3 is consequently financially attractive even with increased fertilizer cost, regardless of the farmer's current fertilizer N use. The fertilizer N rate at maximum GRF was little affected by the upward shift in the production function (Scenario 3 compared to Scenario 1 in **Table 1**). At increased fertilizer cost, the net benefit at maximum GRF was US$140/ha relative to the typical production function at standard fertilizer N cost.

Our experiences across Asia through multiple partnerships within the Irrigated Rice Research Consortium suggest such a large yield increase of 0.6 t/ha at maximum GRF in Scenario 3 would typically not be derived solely by improved management of fertilizer N. It would likely require combining another improved practice with improved N management. For example, the use of a better adapted rice variety, such as with better resistance to local pests and disease or with higher yield potential, could contribute to an upward shift in an existing production function. The intensification of cropping on Asian rice lands with sufficient fertilizer N for relatively high yield has increased the extraction of other nutrients from soil. Zinc, K, and S are increasingly being recognized in major rice-growing areas as important constraints to achieving higher rice yields as fertilizer N management is optimized.

"Increase yield to increase profit" (Scenario 3) can be a much more effective message for farmers than "reduce fertilizer N to increase profit" (Scenario 2). The markedly greater benefit derived from Scenario 3 than Scenario 2 suggests research, extension, and farmers should focus on identifying and overcoming the main field-level constraint to higher yield once N is eliminated as a constraint through profitable N management following SSNM principles (IRRI, 2007; Witt et al., 2007). Our analysis does not consider added costs associated with additional inputs to eliminate the yield-limited constraints. The profits for farmers would obviously depend on added costs, but our analysis clearly shows the markedly greater opportunity with Scenario 3 than Scenario 2.

Scenario 4: Improving use of indigenous N and increasing yield through improved management

In some cases the improvements in management can increase yield in the absence of fertilizer N as well as across all rates of fertilizer N, resulting in an upward shift in the production function as illustrated in **Figure 1g**. This scenario is comparable to Scenario 3, except there is an additional focus on improving management to achieve higher grain yield from the indigenous supply of N. This could include practices that enable either more effective extraction of N from soil or more effective conversion of extracted soil N into grain yield.

The establishment of rice by broadcasting germinated seed on wet soil has gained popularity as a labor saving alternative to manual transplanting. In many instances, Asian farmers, who practice wet seeding, use high seed rates in order to reduce risk and control weeds. This leads to excessive vegetative growth and a relatively low percentage of panicle-bearing tillers. In such a case the optimization of seed rate might increase yield in the absence of fertilizer N and across all rates of fertilizer N.

In the given example, maximum grain yield and net benefit at standard and increased fertilizer N costs relative to Scenario 1 were comparable for Scenario 4 and Scenario 3 (**Table 1**). The adoption of management practices to increase grain yield is vital for high profitability near maximum GRF even with increasing fertilizer cost because irrigated rice farmers in Asia often use fertilizer N near or above the rate for maximum GRF.

Fertilizer Cost and Profit – P and K

The needs of rice for P and K are directly related to grain yield. For each ton of grain yield, a mature crop of modern high-yielding rice typically contains the equivalent of about 6 kg P_2O_5 within its biomass. Hence, a 6 t/ha crop contains plant P equivalent to about 36 kg P_2O_5 at maturity. Two-thirds of this P is in the grain. Therefore, about 4 to 6 kg P_2O_5 are removed per hectare from a rice field for each ton of grain yield, depending on the amount of crop residue retained.

As a general principle, irrigated rice requires about 4 to 5 kg P_2O_5/ha from fertilizer — depending on the amount of straw retained — for each ton of grain yield to balance P removal. A rate of 4 to 5 kg P_2O_5/ha per ton of anticipated grain yield can serve as a general guideline for the essential fertilizer P requirement to maintain soil fertility and achieve high profit for irrigated rice with a history of fertilizer P use (Witt et al., 2007).

The need for fertilizer K depends upon the management of rice straw — which contains 80 to 85% of the K in a rice crop. It also depends on K contained in irrigation water and the K-supplying capacity of the soil, which are typically not known by farmers. Asian rice farmers are often not applying sufficient fertilizer K to balance the K removed in harvested grain and straw. The production of rice consequently relies on the extraction and depletion of K from soil reserves.

As illustrated through Scenarios 3 and 4 in **Figure 1**, further increases in yield are critical to ensuring and maintaining profitability for rice farming with increasing fertilizer costs. The adoption of improved N and crop management practices to increase rice yields will in many cases accelerate the depletion of soil K reserves. As a result, an insufficient supply to rice crops of K, and other nutrient such as Zn and S, could become increasingly important as a constraint to increased yield and profitability for rice farming. If supplies of fertilizer K become inadequate in a country to meet farmer needs, then scientists have an opportunity to provide guidelines, drawing upon SSNM principles, for distributing fertilizer K to achieve greatest yield gains per unit of fertilizer.

The SSNM approach fortunately provides principles to assess nutrient needs and techniques to guide the evaluation and improvement of current practices. Farmers for example can use simple field plot techniques provided through the SSNM approach to assess whether their current fertilizer K use is adequate for high profit and to tailor K fertilization to their field-specific needs (IRRI, 2007).

Conclusions

SSNM provides principles and guidelines for optimizing the rates and timing of fertilizer N at the field level. As fertilizer prices increase, increasing rice yield offers more opportunity than reducing fertilizer use per se to increase profit. Rice farmers should aim to combine improved N management with other management practices that increase profit by overcoming main yield-limiting constraints. As N management is optimized, it becomes increasingly important to rapidly identify and optimally manage other nutrients that become the main yield-limiting constraint. BC

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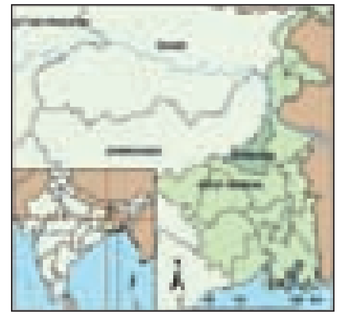
Balancing Sulfur and Magnesium Nutrition for Turmeric and Carrot Grown on Red Lateritic Soil



By P. Bose, D. Sanyal, and K. Majumdar

Increasing rates of S and Mg improved the yield and quality of turmeric and carrot in the depleted red lateritic soils of West Bengal. This trend reversed once the optimum rate of S and Mg application was exceeded, probably due to antagonistic effect of Mg on K uptake.

The deficiency of secondary nutrients, namely S and Mg, is increasing in India. One survey found 240 districts to be generally deficient in S, and the problem is spreading (Sakal et al., 1981; Singh, 1998). A recent effort by the Fertiliser Association of India, The Sulphur Institute, and the International Fertilizer Industry Association (FAI-TSI-IFA) studied 27,000 samples distributed over 12 states and found that over 40% of samples were deficient in available S and another 35% potentially deficient. More than 70% soil samples taken from Uttar Pradesh, Madhya Pradesh, Maharashtra, Orissa, Jharkhand, West Bengal, Andhra Pradesh, and Karnataka were low to medium in available S (Biswas et al., 2004). The main reasons behind such widespread deficiency are over-dependence on "S-free" fertilizers, depletion of soil S with continuous cropping, sizable areas (around 27% of the country's gross cropped area) under pulses and oilseeds that have a higher requirement for S, loss of soil S due to leaching, soil erosion, lack of organic manure addition, and low awareness of farmers towards use and importance of S in agriculture.

Similarly, Mg deficiency can be a problem in India. Cases are found in the acid laterite soils of Kerala, the Malnad area of Karnataka, Nilgiris in Tamil Nadu, certain areas of Andhra Pradesh under cotton, citrus, and banana, in Goa, parts of Himachal Pradesh, the red lateritic zone of West Bengal and throughout the northeastern region of India. Magnesium can be leached more easily compared to Ca, making acid, sandy soils particularly vulnerable to Mg deficiency. The deficiency also becomes severe under intensive cultivation. With heavy use of NPK fertilizers and manures, sometimes a depressing effect of K application on yield is the result of Mg deficiency. While possibly not a problem at low yields, Mg deficiency can become a problem at high yield levels, as in the case of tea estates in southern India (Verma, 1993). The Mg content of soils depends upon the nature of the parent material, the degree of weathering, soil texture, rainfall, intensity of cropping, and management practices. Magnesium deficiency is actually more widespread than is realized due to inadequate scientific data about the effect of applications of Mg fertilizers on crops, particularly in India.

Birbhum district of West Bengal is located within the leached red and lateritic soil belt and has wide-spread N, P, K, S, and Mg deficiencies. The agro-climatic conditions in Birbhum are highly suited for cultivation of carrot and turmeric, but its soils require careful nutrient management for optimum yield. Two experiments were undertaken to study the effect of soil test based fertilizer application, with special reference to S and Mg, on growth, yield, and quality of carrot (cv. Early Nantes) and turmeric (cv. Lakadong, Shillong).

Inspecting the turmeric experimental plot are, from left, Dr. Majumdar, Mr. Bose, and Mr. Roy, the cooperating farmer.

Turmeric (*Curcuma longa)* is a herbaceous, rhizomatous spice crop, native to tropical Southeast Asia. India is the largest producer of turmeric in the world, with 75% of world output. Turmeric is a heavy nutrient using crop and responds well to fertilizer application. Carrot (*Daucus carota* L.) is one of the major vegetable crops of India. It is grown in the spring-summer season in temperate regions and during winter in tropical and subtropical parts of the world.

Both the experiments were laid out in a randomized block design with seven treatments and three replications. In the case of turmeric the plot size was 7.0 m x 5.0 m, while for carrot the plot size was 3.5 m x 3.0 m. Uniform cultural practices and plant protection measures were undertaken for all the treatments. Randomly collected soil samples (0 to 15 cm depth) were analyzed and yield target-based recommendations were developed following Agro Services International, Inc. analytical methods (Portch and Hunter, 2002).

All the plots in the turmeric experiment received 150 kg/ha N and 50 kg/ha P_2O_5 and 190 kg K_2O/ha on the basis of soil test values. For carrot, a constant level of 80 kg/ha N and 50 kg P_2O_5/ha and 120 kg K_2O/ha were applied to all the plots on the basis of soil test values. Variable rates of S (0 to 66 kg/ha) and Mg (0 to 33 kg/ha) constituted the seven treatments for both the crops (**Table 1**). No S and Mg were applied in the control plots.

Turmeric received the full dose of P during land preparation while half the N and K were applied one month after transplanting. The remaining N and K were applied 4 months after transplanting. Sulfur and Mg were applied in two equal

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

Table 1. Turmeric rhizome characteristics as influenced by different levels of S and Mg treatments.

Treatments	No. of mother rhizome/plant	Weight of mother rhizome, g	No. of primary fingers	Length of primary finger, cm	Weight of primary finger, g
S_0Mg_0#	4.3	66.9	9.3	4.8	72.2
$S_{11}Mg_{5.5}$	4.7	69.2	15.7	4.8	108.0
$S_{22}Mg_{11}$	4.7	74.9	17.3	5.0	109.7
$S_{33}Mg_{16.5}$	5.0	76.1	18.7	5.1	126.4
$S_{44}Mg_{22}$	5.3	150.3	24.0	5.7	204.1
$S_{55}Mg_{27.5}$	4.7	138.7	21.3	5.4	202.9
$S_{66}Mg_{33}$	4.3	119.3	20.0	5.4	200.1
C.D. (at 5 %)*	NS	30.1	NS	NS	39.4

values in subscripts are applied rates of S and Mg in kg/ha; * NS – not significantly different.

splits at one and four months after transplanting. The full dose of P, half N and half K were applied to carrot at land preparation. The remaining N and K were applied one month after transplanting. Sulfur and Mg were applied in two equal splits at land preparation and one month after transplanting.

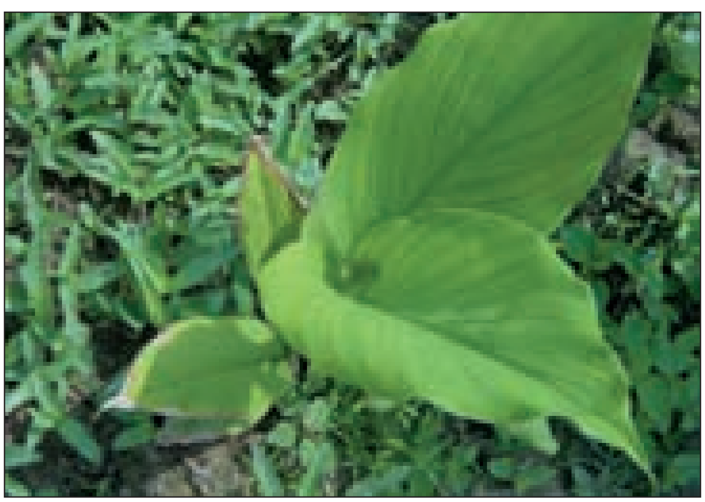
The Total Soluble Solid (TSS) content of carrot was determined with an ERMA hand refractometer, calibrated at 20º C (A.O.A.C, 1984; Mitra and Sanyal, 1990). The data were corrected as per the standard temperature correction table. The values obtained were recorded as ºBrix, which are essentially percent soluble solids present in the extracted juice. Since 90% of soluble solids in the juice are sugar, a high TSS content in carrot suggests better quality. The curcumin content of turmeric was determined following the method as described by Sadashivam and Manikam (1992).

Turmeric—Application of different levels of S and Mg did not have any significant effect on the vegetative growth of the plants. Though maximum number of mother rhizomes and primary fingers, as well as highest length of primary fingers, was noted at 44 kg/ha of S and 22 kg Mg/ha, the effects were not statistically significant (**Table 1**). There was a significant increase in the weight of the mother rhizome at the above dose, which then declined with further increases in S and Mg levels. Significant variation in weight of primary fingers was observed due to S and Mg applications, also peaking with 44 kg S/ha and 22 kg Mg/ha.

Results show that inclusion of S and Mg in the fertilization schedule dramatically improved the fresh yield (**Table 2**). Maximum fresh yield of 26 t/ha was obtained with 44 kg S/ha and 22 kg Mg/ha, along with soil test based N, P, and K application rates. The average yield of dry turmeric in West Bengal is around 1.5 t/ha. Assuming dry yield to be about 20 to 30% of the fresh yield, the maximum dry yield in this study was more than 6 t/ha. No significant effect was found on percent dry weight or curcumin content.

Carrot—Different levels of S and Mg did not have any significant influence on the vegetative parameters of the carrot. No perceptible variation was observed in fresh weight of leaves at different levels of S and Mg application. There was also no significant variation in root characteristics of carrot due to S and Mg application. However, a significant variation in yield per plant as well as projected yield per hectare was noted at various levels of S and Mg application in carrot (**Table 3**). The variety of carrot grown in this experiment has a yield potential of about 15 t/ha under West Bengal conditions, but the average yield in farmers' plots were about 5 to 6 t/ha. The current experiment showed that S and Mg strongly influenced carrot yield, which nearly doubled after addition of the first increment of S and Mg (**Table 3**). Maximum yield of 13.6 t/ha was obtained at 44 kg S and 22 kg Mg/ha, which is probably the optimum rate under the experimental conditions. Any further increase in S and Mg rates caused a sharp decline in yield.

Root and tuber crops exhibit a distinct source-sink competition between vegetative growth and storage tissue growth for a fairly long period. The effects of mineral nutrient supply on crop yield response characteristics are often a reflection of sink limitations imposed by either a deficiency, or an excessive supply, of mineral nutrients during certain critical periods



Potassium deficiency in tumeric at an early stage in the experimental plot.

Table 2. Yield and quality of turmeric as affected by different levels of S and Mg.

Treatments	Fresh yield/plant, g	Fresh yield, t/ha	Dry weight, %	Curcumin, %
S_0Mg_0#	197.1	13.8	23.5	4.8
$S_{11}Mg_{5.5}$	203.1	14.6	26.0	5.1
$S_{22}Mg_{11}$	208.9	14.2	25.4	5.2
$S_{33}Mg_{16.5}$	223.4	15.6	24.7	5.2
$S_{44}Mg_{22}$	369.9	25.9	26.3	6.4
$S_{55}Mg_{27.5}$	351.9	24.6	26.6	6.1
$S_{66}Mg_{33}$	336.4	23.6	23.1	6.1
CD (at 5 %)*	52.4	3.4	NS	NS

values in subscripts are applied rates of S and Mg in kg/ha; * NS – not significantly different.

Table 3. Yield and TSS content of carrot as affected by S and Mg application.

Treatments	Fresh yield/plant, g	Projected fresh yield, t/ha	TSS content, °Brix
S_0Mg_0#	22.9	5.6	9.1
$S_{11}Mg_{5.5}$	41.8	10.1	9.5
$S_{22}Mg_{11}$	46.3	11.3	9.7
$S_{33}Mg_{16.5}$	49.9	12.1	10.3
$S_{44}Mg_{22}$	56.1	13.6	10.7
$S_{55}Mg_{27.5}$	44.4	10.8	11.1
$S_{66}Mg_{33}$	36.3	8.8	11.0
CD (at 5 %)	4.7	1.2	0.2

values in subscripts are applied rates of S and Mg in kg/ha.

of plant development. The current experiment showed that yield of both the crops declined with any further increase of S and Mg rates beyond 44 kg/ha of S and 22 kg/ha of Mg. This could be due to the antagonistic relations between K and Mg. In the literature, the antagonistic effect of K on Mg is widely reported. Potassium induced Mg deficiency in Arabica coffee was reported by Rao (1968) at leaf K levels of 2.48%, Mg levels of 0.21%, and at a K:Mg ratio of 11.8. Reports of antagonistic effects of Mg on K are few. However, Mg-induced K deficiency was observed in coffee by Rao (1968) at 0.4% leaf Mg and 1.2% leaf K level under field conditions with continuous use of dolomite as an amendment along with concurrent foliar sprays of magnesium sulfate. Probably such antagonism was significant in this study at application rates of more than 22 kg/ha of Mg, which reduced K uptake and caused losses in yield. Similar antagonism between Mg and K was found in mature tea experiments at Annamallais, South India (Verma, 1993).

The results of this research clearly show that S and Mg were deficient in the carrot and turmeric crops at this location. However, over application of these nutrients can result in yield declines, demanding that careful attention be paid to the effect of soil test S and Mg levels when determining fertilizer additions. BC

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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

Implications of Asian Soybean Rust in Nutrient Management — Research Update

By P.E. Fixen, R.W. Schneider, D.L. Wright, A.P. Mallarino, K.A. Nelson, S.A. Ebelhar, and N.A. Slaton

The increasing threat of Asian soybean rust (ASR) in the U.S. has stimulated significant research on control of soybean diseases. By the end of the 2007 growing season, ASR was verified as far north as central Iowa, where it was detected in a few isolated fields with no impact on yield. In several regions, growers and their advisers debated as to whether the yield loss threat of ASR and other diseases justified the cost of fungicide application. An understanding of the impact of cultural practices on disease development is helpful in such situations. Studies over the last couple of years have demonstrated that nutrient management can at times influence soybean disease development. However, much is yet unknown as to specific effects and if fertilizer BMPs need to be altered when ASR is present or a threat.

Much is known about the influence of plant nutrition on susceptibility and tolerance of crops to diseases (Datnoff et al., 2007). For example:

- K deficiency causes or contributes to thin cell walls, weakened stalks and stems, smaller and shorter roots, sugar accumulation in the leaves, and accumulation of unused N, all of which encourage disease infection (PPI, 1998).
- Application of Cl, usually in the form of KCl (muriate of potash), has been shown to reduce the severity of numerous fungal diseases (Fixen, 1993).
- Although studies have shown that several micronutrients can be involved in development of resistance in plants to both root and foliar diseases, Mn is thought to be the most important (Graham and Webb, 1991). As with Cl, studies have shown differences among varieties in response and some have observed that newer glyphosate-resistant soybean varieties have a reduced capacity to either take up or translocate Mn (Gordon, 2007).
- The likelihood of stem and leaf disease problems increases with crop stress and nutrient shortages and imbalances. Leaf rust in winter wheat has been reduced and yields increased by providing adequate P and K nutrition to the crop (PPI, 1999). A study on the effect of NPK fertilization on ASR-infected soybeans in the Philippines showed some rust suppression when either P (superphosphate) or K (KCl) was applied, but showed the greatest suppression when both nutrients were used.
- Independent anecdotal reports exist of ASR suppression by application of KCl and by application of micronutrients in Brazil.

With the threat and the reality of ASR presence in the U.S., it is reasonable to reevaluate the impact of plant nutrients on soybean diseases and their management. This led IPNI ...through its research affiliate, the Foundation for Agronomic Research (FAR)...to support studies in several states evaluating the influence of nutrient application on ASR and other soybean diseases. In this article, we report on progress while not drawing conclusions. The intent is to offer a "heads up" on some potential effects to growers, crop advisers, and researchers as we continue to study and manage soybean diseases, especially ASR.

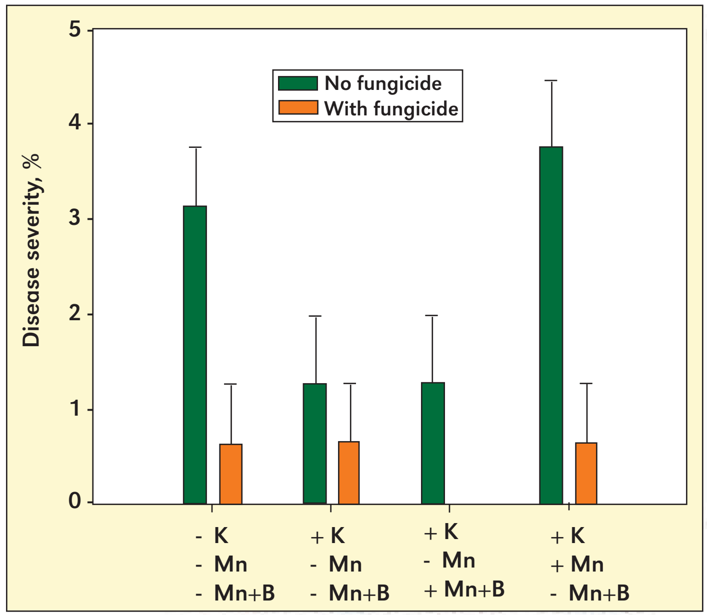
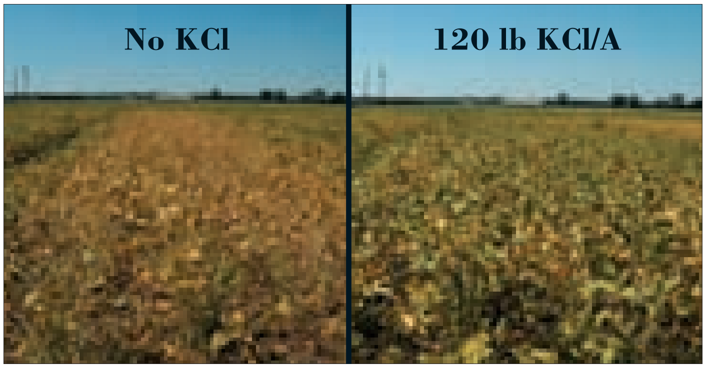


Figure 1. Effects of K, Mn, B, and fungicides on severity of ASR in soybean at Baton Rouge, Louisiana, in 2005.

Louisiana

Studies were initiated at the Louisiana State University (LSU) Agricultural Center in Baton Rouge in 2005. Hurricanes Katrina and Rita prevented the crop from reaching maturity, however, some disease incidence data were collected. Factors evaluated were preplant KCl applied at a rate of 125 lb/A and foliar application of either 0.5 lb Mn/A or 0.5 lb Mn plus 0.25 lb B/A at V4 and V10 growth stages. These fertilizer treatments were compared to Headline® and Folicur® fungicides applied at R3 and R6 growth stages. ASR did not develop until mid-November in 2005 when plants were in the late R6 growth stage and severity remained low. Though incidence was low, fungicide application reduced ASR severity across all treatments (**Figure 1**). KCl also appeared to reduce severity in two out of three treatments, while the micronutrient applications did not reduce severity. Cercospora leaf blight also was present in 2005 and both fungicide and KCl application reduced

Abbreviations and notes for this article: K = potassium; Cl = chloride; N = nitrogen; P = phosphorus; Mn = manganese; B = boron; BMPs = best management practices; ppm = parts per million.



Influence of preplant application on ASR in nutrient study at Baton Rouge, Louisiana, 2007 (Photo by R.W. Schneider).

incidence. However, incidence of this disease also was quite low, with the untreated check having a severity of only 5% (data not shown).

Severe drought in 2006 resulted in abandonment of the plots, but in 2007 a new study was established. The study compared preplant application of KCl and $CaCl_2$, preplant and sidedress application of $CaCl_2$, and evaluated the effects of foliar B+Mn application as well as 5 or 10 lb/A of urea N at the R1 growth stage. ASR incidence in 2007 was severe with 100% of leaf area in the untreated check plots being affected by the mid to late R6 growth stage, which occurred on October 3. The micronutrient application did appear to reduce incidence, especially in the upper canopy, while the sidedress Cl applications did not (**Table 1**).

Application of preplant KCl reduced severity in the upper canopy with the $CaCl_2$ application having a similar effect, indicating that the effect of KCl was due to Cl rather than K (**Figure 2**). The low rate of urea appeared to also reduce severity somewhat, but no effect was noted for the high rate (data not shown). Yield data from these studies were not available at the writing of this article.

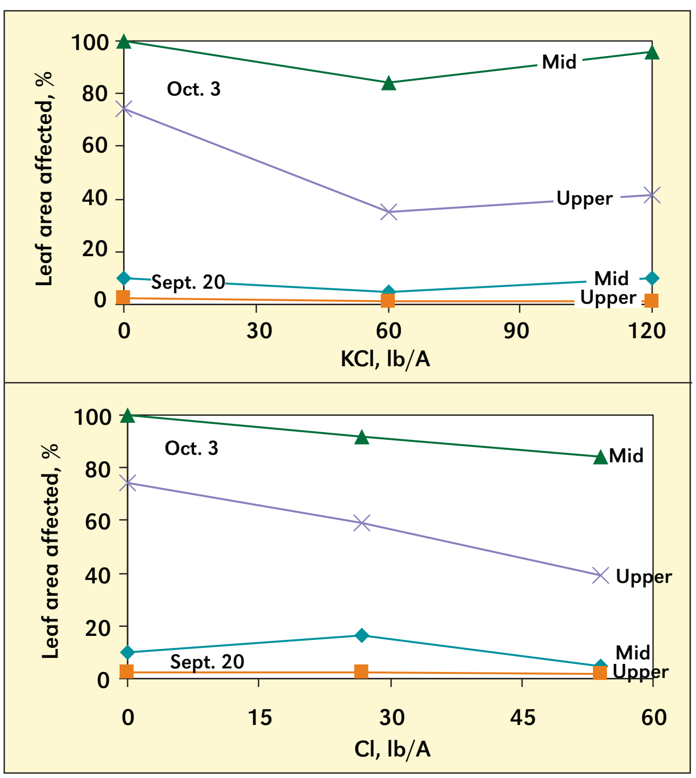


Figure 2. Influence of preplant application of K and/or Cl on leaf area affected by ASR at Baton Rouge, Louisiana, in 2007.

Table 1. Influence of foliar micronutrient application or sidedress Cl at R1 on leaf area affected by ASR at Baton Rouge, Louisiana, in 2007.

Treatment[1], lb/A	Sept. 20, early R6		Oct. 3, mid-late R6	
	Mid	Upper	Mid	Upper
	----- % leaf area affected -----			
No micros	10	2	100	74
0.25B+0.50Mn	11	2	88	47
No sidedress Cl	11	2	93	52
With sidedress Cl	8	1	100	80

[1]Averaged across other treatments.

Florida

Due partly to the pattern of ASR development, studies were initiated in 2006 by the University of Florida at the Quincy research center. Factors evaluated were preplant KCl and $CaCl_2$ at rates of 50 and 100 lb Cl/A and foliar application of B plus Mn at the R2 growth stage. ASR was first observed on October 9 in 2006, however, no effect of KCl or $CaCl_2$ on ASR or grain yield was observed. The micronutrient application did result in reduction of ASR severity and a significant grain yield increase (**Table 2**). No 2007 data were available at the writing of this article.

Missouri

Studies were conducted by the University of Missouri at Novelty and Portageville in 2006 and 2007. Factors evaluated were preplant KCl applied according to soil test-based recommendations and foliar KCl at a rate of 27 lb/A applied with or without fungicides (Headline® or Quadris®) at V4 or R4 growth stages. Diseases evaluated included frogeye leaf spot and Septoria brown spot, though incidence never exceeded 10%. ASR was not present. At the Novelty location, preplant KCl significantly reduced incidence of frogeye and Septoria while foliar application had much less to no effect (**Figure 3**). Preplant KCl increased yield by 5.1 bu/A; foliar KCl increased yield 1.6 bu/A. At the Portageville location, preplant KCl increased yield over 5 bu/A, but there was no yield response to fungicides or foliar KCl. Effects of treatments on disease incidence were variable and inconsistent.

Table 2. Influence of foliar micronutrient application at R2 on ASR severity at Quincy, Florida, in 2006.

Treatment[1], lb/A	ARS Severity Nov. 2	Nov. 9	Nov. 17	Grain yield, bu/A
	-------- % --------			
No micros	17	36	88	22.2
0.25B+0.50Mn	14	18	70	25.2
LSD_{05}	NS	10	17	1.5

[1]Averaged across KCl and $CaCl_2$ treatments.

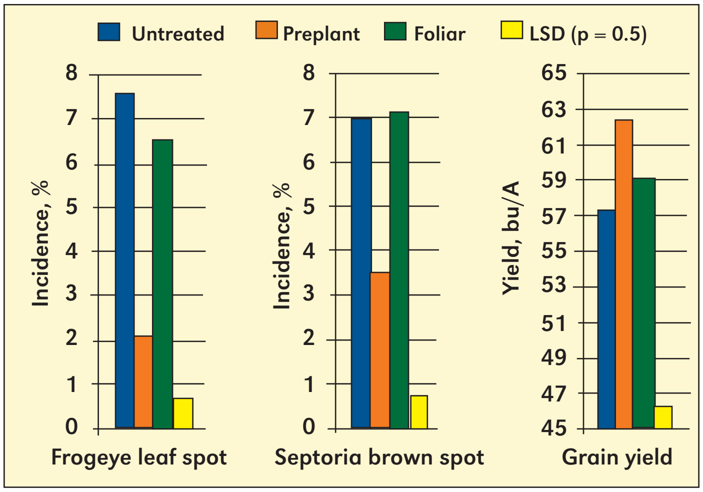


Figure 3. Influence of KCl application on disease incidence and soybean yield at Novelty, Missouri (Avg of 2006 and 2007).

Iowa

Two studies were conducted by Iowa State University from 2005 to 2007. The 2007 data are not yet available. Factors evaluated were foliar application of 3-18-18 and UAN in five trials (two locations in 2005 and three in 2006) and preplant KCl for chisel plow and no-till systems in ten trials (five locations in 2005 and 2006). Diseases evaluated were frogeye leaf spot, Septoria brown spot, and Cercospora (ASR was not present). Fungicide application showed good potential for increasing soybean yield, but foliar fertilization did not and had no consistent effect on measured foliar diseases. At the K study, fertilization increased grain yield in both tillage systems at three locations with soil-test K < 170 ppm and significant disease incidence was observed at only one location in 2005 and two in 2006. Significant K effects on disease incidence were measured at two locations in 2006. At the Northeast Farm, incidence or severity of the three diseases was reduced by KCl application, especially brown spot incidence in the no-till system (**Table 3**). Grain yields were increased by 4 to 5 bu in the chisel system and by 8 bu/A in the no-till system. At the Northern Farm location, brown spot was reduced by KCl in the no-till system, but not in the chisel system (**Figure 4**). Frogeye and Cercospora were reduced similarly in both tillage systems. Grain yields were increased by KCl in both systems.

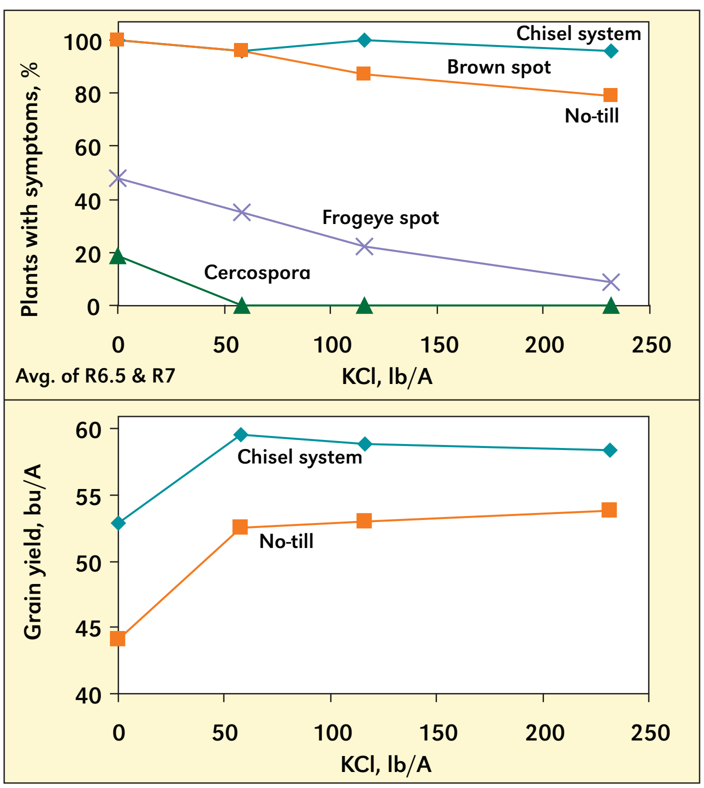


Figure 4. Influence of KCl fertilization on three diseases and yield in Iowa (Northern Farm, 2006).

Table 3. Influence of KCl fertilization on brown spot and grain yield in Iowa (Northeast Farm, 2006).

	Chisel		No-till	
KCl rate, lb/A	Incidence, %	Yield, bu/A	Incidence, %	Yield, bu/A
0	92	56.3	95	52.1
58	83	61.5	92	57.9
116	82	59.7	78	60.1
116[1]	88	61.4	67	60.5

[1]Deep-band K fertilizer placement.

Illinois and Arkansas

Studies are also ongoing by the University of Illinois and by the University of Arkansas. The Illinois studies are evaluating application of KCl, K_2SO_4, foliar B, and foliar Mn on both glyphosate-resistant and non-glyphosate-resistant varieties. The Arkansas studies are examining P and KCl applications. In general, diseases at these locations were slight to none except at one Illinois location in one year where fungicide gave a 7 bu/A response, mostly from frogeye suppression. However, none of the fertilizer treatments reduced disease severity. No yield increases to fertilizer treatments were measured in Illinois while one 8 bu/A response to K was measured in Arkansas. However, it did not appear to be related to disease suppression.

Summary and Questions

Based on these preliminary results, here are some observations.

- KCl application reduced:
  - frogeye leaf spot and Septoria brown spot in Iowa and Missouri, but not in Illinois;
  - Cercospora leaf blight in Iowa and Louisiana;
  - ASR in Louisiana ($CaCl_2$ effect was similar), but not in Florida.
- Mn + B application reduced ASR in both Louisiana and Florida.

In some situations, nutrient application in today's cropping systems appears to reduce soybean fungal disease severity, but does not substitute for fungicides when disease pressure is severe. In epidemiological terms, disease onset was delayed, and the rate of disease development was reduced, although disease severity at the end of the season may not have differed among treatments. However, an improved understanding of these nutrient-disease interactions may offer an opportunity for more cost effective disease management. These studies have clearly identified specific questions that need to be addressed.

- To date at responsive sites, Mn and B have been applied together. Which of these nutrients is responsible for the effect?
- KCl application has suppressed disease. Is this a K effect or a Cl effect or both?
- Do disease considerations alter BMPs for nutrients? For example, if the KCl effect is due to Cl or tied to recently applied K, potash applications may need to be made directly to soybean.
- Are there interactions among nutritional status and predisposing stressors such as water stress, soil compactions, and others? BC

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Note: Proceedings from the third National Soybean Rust symposium are now posted on the Plant Management Network's publicly available Soybean Rust Information Center at this URL:

http://www.plantmanagementnetwork.org/infocenter/topic/soybeanrust/2007

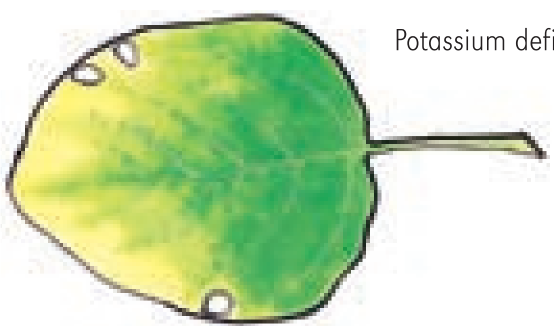
Recognizing Soybean Field Problems

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.

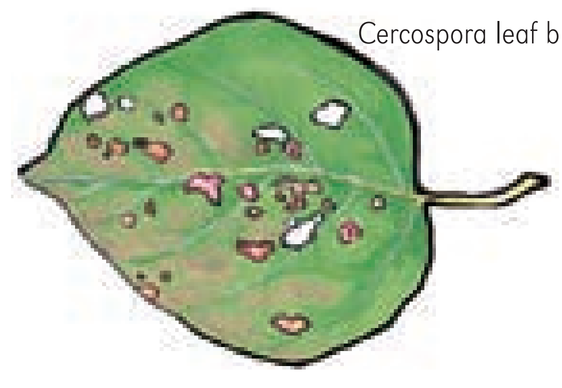
Shown on this page are a few examples illustrating symptoms from the IPNI publication titled *Be Your Own Soybean Doctor*. It is intended to help growers, consultants, and others in becoming more familiar with symptoms of nutrient deficiencies, toxicities, diseases, and other disorders in soybean production. 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.

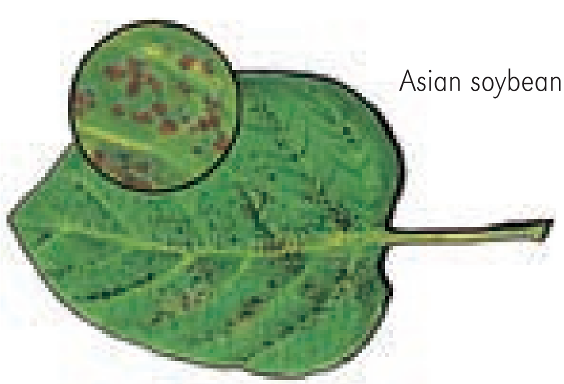
Contact: Circulation Department, IPNI, 3500 Parkway Lane, Suite 550, Norcross, GA 30092-2806; phone 770-825-8082 or 825-8084; fax 770-448-0439. BC



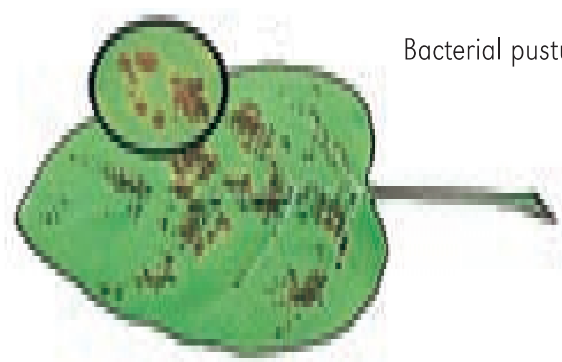
Potassium deficiency



Cercospora leaf blight/Frogeye



Asian soybean rust



Bacterial pustule

Ernst Walter Mutert, 1940-2007: Memoriam

Dr. Ernst Mutert's many friends and colleagues in Southeast Asia, Germany, the USA, and around the world were saddened to hear of his death on October 27th after a long illness. Dr. Mutert was Director of the East and Southeast Asia Program of the Potash & Phosphate Institute (PPI) and International Potash Institute (IPI) in Singapore from 1994 to 2002.

He was born in Osnabrück in 1940 and, after gaining practical experience on his family farm and farms in northern Germany, took his first degree at the College for Agricultural Science and Technology in Osnabrück and a Diploma in Plant Production at the Christian-Albrecht University in Kiel, where he also completed his doctorate in soil survey in 1980.

Dr. Mutert's first appointment was to the Chamber of Agriculture in Oldenburg from 1965-1968 as an adviser on soil fertility. His first foray into the world of overseas agriculture was as a soil surveyor in Libya in 1980-1981, where he was greatly entranced by the desert world. From 1981-1991 Dr. Mutert worked for the renowned Büntehof Agricultural Research Station of Kali und Salz in Hanover, Germany, and its extension service for fertilizer use on soils and in cropping systems in the tropics and subtropics. During frequent travels worldwide, he initiated fertilizer experiments on farms in close collaboration with national and international research stations. These visits were combined with lectures on soil fertility, delivered with infectious passion to students and advisers, and the dissemination of his own papers on balanced mineral crop nutrition. While at Büntehof, Dr. Mutert was also a representative of IPI in Berne, Switzerland, working in close contact with Dr. Helmut von Uexküll, then the PPI/IPI representative in Southeast Asia.

In 1991, Dr. Mutert was selected to succeed Dr. von Uexküll as Director of the joint program of PPI and IPI based in Singapore. Dr. Mutert worked tirelessly and continuously to bring attention to and develop pragmatic agricultural technology for Southeast Asia's uplands, using his practical experience from South Sumatra. He championed the case for the use of P fertilizer to bring fertility to Southeast Asia's low fertility status upland soils and to increase the productivity of small-scale farmers in Indonesia, Vietnam, Burma, Philippines, Cambodia, and Laos.

He campaigned hard, and at first alone, to achieve a place for mineral fertilizers in Vietnam's program for agricultural improvement following Doi Moi (or 'change and newness' to create a 'market economy with socialist direction') by forging close ties with Vietnam's leaders in agriculture policymaking. In partnership with Vietnamese colleagues who became close friends, Dr. Mutert supported a nationwide program on balanced fertilization between 1994 and 2002, during which time Vietnam became a net rice exporter and achieved world significance as a coffee producer. Many will remember his ability to motivate people to improve the productivity of these systems while standing knee-deep in the mud or on steep slopes in the uplands with words from outside the science lexicon, such as: "I believe it can be done and we shall succeed if we implement the ideas we developed together."

Dr. Mutert

Dr. Mutert (center) was always popular among the people in Southeast Asia and other regions where he worked.

Dr. Mutert was quick to recognize the importance of building new initiatives to raise productivity of Southeast Asia's lowland rice fields after the impetus of the green revolution began to wane in the 1980s. He was instrumental in organizing support for a major research program at the International Rice Research Institute in Los Baños that included significant contributions from IFA, IPI, and PPI. He was also a great supporter of oil palm development in Southeast Asia, recognizing the importance of developing sustainable oil palm production systems. He was a valued consultant to a number of leading plantation companies and research stations in Malaysia and Indonesia.

A relentless traveler, Dr. Mutert was able to survive on the road for extended periods with his battered pilot case as his only companion. He was able, as if by magic, to draw a smart suit and shoes or field clothes and a pair of training shoes from his bag as the circumstances required. On field trips, he could move seamlessly from a bed on the floor of a farmer's house in a remote part of Sumatra to a meeting with the Minister of Agriculture in Jakarta the following day. Although a shy man, Dr. Mutert had the ability to bring out the most social side of both old friends and new acquaintances. He loved the natural world and the farmer's field, and was a natural philosopher. He will be remembered by his many friends of all ages for long evening discussions on 'agri-culture', with occasional digressions into a myriad of other topics. In a world now dominated by specialists, we remember Dr. Mutert's special ability to contribute to and participate in discussions covering the length and breadth of issues relating to agriculture and rural development. We send heart-felt condolences to his family in Germany. BC

— Prepared by Dr. Thomas Fairhurst, Singapore, with contributions from Dr. Mutert's many friends and colleagues.

9th International Conference on Precision Agriculture July 20-23, 2008/InfoAg 2009 July 14-16, 2009

"Individuals involved in precision agriculture are encouraged to mark their calendars with the dates of two important events for 2008 and 2009," notes Dr. Harold F. Reetz, of the International Plant Nutrition Institute (IPNI) and Foundation for Agronomic Research (FAR).

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. Reetz 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 website: **www.icpaonline.org**.

The next Information Agriculture Conference is scheduled for July 14-16, 2009, in Springfield, Illinois. "These two events have occurred in alternating years for the past several years. While they appeal to somewhat different audiences, there are individuals who plan to attend both," Dr. Reetz explains. The InfoAg Conference is oriented more to practical application of precision farming, data management, and technology systems for agriculture. Find out more at the website: **www.infoag.org**. 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

Better Crops with Plant Food in a New Era

In the classic story by Washington Irving, a character named Rip Van Winkle takes a 20-year nap under a tree and wakes up to find that he has missed the American Revolution, plus numerous other unexpected changes in his village and surrounding countryside. When he returns, his environment is not the same as he remembered and he encounters a new generation of people busily going about their work. It is a different world.

Some might see a parallel to this story in agricultural production and information. While many basic concepts and scientific principles remain unchanged through time, most technology, market conditions, and management practices continue to evolve from what would have been considered state of the art just a few years earlier.

Just over one year ago, the International Plant Nutrition Institute (IPNI) became the owner and publisher of *Better Crops with Plant Food*. However, this magazine has a long and proud history of publishing sound, dependable, accurate, and useful information on crops, soils, plant nutrition, conservation, and related subjects. Many readers may not realize that *Better Crops* first began publication in 1923. *Plant Food* was the name of a second magazine that first came into print in January 1926. Because the mission of the two publications was so similar and for other reasons, the two magazines were combined and the first issue of *Better Crops with Plant Food* was published in July 1927. That was over 80 years ago. At that time, the main audience was in the United States…now we communicate to readers around the globe in print and through the worldwide web (check our website at **www.ipni.net**). IPNI now also publishes *Better Crops-China* and *Better Crops-India*.

Looking back through past issues of *Better Crops with Plant Food*, it is fascinating to revisit the introduction and evolution of concepts and ideas as reported through articles based on agronomic research. Some today might ask: "Don't we already know all there is to know about fertilizers…nitrogen, phosphorus, potassium, secondary nutrients, and micronutrients?" The answer is clearly "No". As part of the mission of IPNI, *Better Crops with Plant Food* seeks to report new information based on scientific discovery and evaluation. IPNI programs apply this knowledge in ways that are protective of the environment, preservative of natural resources, economically sustainable, and socially acceptable.

Tremendous progress in agriculture, the fertilizer industry…and the world…has occurred in recent decades. If you are just waking up from a 20-year nap, you may have a lot of reading to do. Welcome to the world of *Better Crops with Plant Food* in 2008.

Don Armstrong

Donald L. Armstrong, Editor

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