BETTER CROPS
WITH PLANT FOOD

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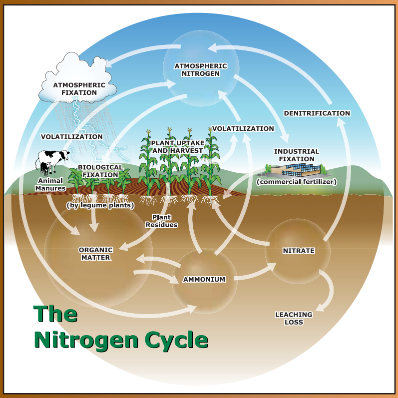

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WITH PLANT FOOD

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C O N T E N T S

Vladimir Nosov Joins Staff of IPNI as Regional Director, Southern and Eastern Russia

Dr. Vladimir Nosov

Dr. Vladimir Nosov has joined the staff of IPNI as Regional Director for Southern and Eastern Russia, effective August 1. He will be based in Moscow, working in coordination with Dr. Svetlana Ivanova, IPNI Vice President, Eastern Europe and Central Asia.

"This announcement marks an important step forward in our effort to encourage meaningful agronomic education and research efforts within Russia. This is a vital agricultural region and the time is right for enhanced crop productivity and efficiency," said Dr. Terry L. Roberts, IPNI President. "With his unique set of skills and knowledge, Dr. Nosov will be well suited for this challenge."

In 1997, Dr. Nosov received his Ph.D. in Soil Science and Agricultural Chemistry at Lomonosov Moscow State University, Faculty of Soil Science, Department of Soil Chemistry. Earlier, he earned his M.Sc. at the same university in 1994.

From 2003 to 2008, Dr. Nosov served in the Marketing Department of the International Potash Company, based in Moscow. His duties included global market research on potash and dry bulk fertilizers. He was named acting head of the department for 2007-2008 (6 months). From 2003 to 2006, he was a Vice President (Agriculture) of the Union of Producers and Exporters of Potash and Salt, based in St. Petersburg. During this time he was also a member of the managing committee of the International Potash Company-Indian Potash Ltd. Potash Promotion Project. From 2003 to 2008, he was also active as Coordinator for the International Potash Institute (IPI) in India, Bangladesh, and Sri Lanka, related to potash fertilizer use in South Asian agriculture.

Previously, Dr. Nosov was Scientific Officer at Lubertsy Agricultural Research Station in Russia from 1998 to 2002, while also serving as Assistant Coordinator, Former Soviet Union, for IPI.

Dr. Nosov is the author/co-author of 60 publications on the behavior of potassium in soils and on the efficiency of potash fertilizer application. He is editor of two books on mineral fertilizer use, organizer of more than 20 field days for farmers, and a participant in numerous seminars, conferences, and agricultural fairs. He has an extensive list of published research papers, as well as proceedings of symposiums, conferences, and workshops, review papers, and electronic publications. BC

T. Satyanarayana Joins Staff of IPNI as Deputy Director, India Program-South Zone and Sri Lanka

Dr. T. Satyanarayana

Dr. T. Satyanarayana has joined the staff of IPNI as Deputy Director, India Program-South Zone and Sri Lanka, effective November 1, 2008.

"Dr. Satyanarayana has extensive knowledge and experience related to agricultural products as well as expertise in farm technology information transfer," said Dr. Terry L. Roberts, IPNI President. "His skills and talents will be an excellent match for the responsibilities in this important region of India."

In 2005, Dr. Satyanarayana received his Ph.D. degree from the Indian Agricultural Research Institute (IARI) in New Delhi. His Ph.D. research project was "Release and uptake of phosphorus from some organic manures under wheat-blackgram crop sequence using isotopic tracers." Previously, he received his M.Sc. degree at Dr. Y.S.P.U.H. & F. in Himachal Pradesh, with a thesis on nutritional status of apple orchards. In 1998, he completed his B.Sc. (Ag) at Tamil Nadu Agricultural University.

In his most recent employment, Dr. Satyanarayana was Deputy Manager-Business Development & Agri Technical Services, with Shriram Fertilizers & Chemicals, DSCL. In that role, he was involved with identifying emerging trends in agriculture and other allied businesses, imparting training, providing technical input for literature and information materials on various products, and drafting and publishing newsletters and technical bulletins. Among many other achievements, he generated soil fertility maps for zinc and sulphur and introduced new products for deficient areas, introduced four new molecules in crop care chemicals, and developed a video titled "Sahi Raah" on integrated plant nutrient management. He was responsible for coordinating the operations of 110 Shriram Krishi Vikas Kendras (SKVKs), meant for reshaping the lives of Indian farmers through the transfer of location-specific, need-based farm technology.

From 2005 to 2007, Dr. Satyanarayana worked as Deputy Manager-Regulatory Affairs, with Coromandel Fertilisers Ltd., Hyderabad. His responsibilities involved product development (including field trials), as well as data generation for new product registration, and conducting crop seminars and farmer meetings.

Dr. Satyanarayana was also a Senior Research Fellow at IARI from July 2001 to August 2002 and worked on projects related to the rice-wheat cropping system. He is author or coauthor of several research publications. BC

2008 Scholar Award Recipients Named by International Plant Nutrition Institute

The 2008 winners of the Scholar Award sponsored by the International Plant Nutrition Institute (IPNI) have been selected. The awards of US$2,000 (two thousand dollars) each are conferred to deserving graduate students in sciences relevant to plant nutrition and management of crop nutrients.

"We received a significant number of applications for the Scholar Award and were impressed with the academic records, research programs, and other credentials of the graduate students," said Dr. Terry L. Roberts, IPNI President. "The academic institutions these young people represent and their professors and advisers can be justifiably proud."

A total of 14 (fourteen) graduate students were named to receive the IPNI Scholar Award in 2008. They are listed below by region and university/institution.

North America: Carolina Medina, University of Florida; Trenton Roberts, University of Arkansas; Darrin Roberts, University of Nebraska; Fernando Salvagiotti, University of Nebraska; Mark Slavens, Cornell University; Amy Burton, Pennsylvania State University.

China: Xiaofeng HU, Southwest University; Xiaokun LI, Huazhong Agricultural University; Wenjuan LI, Graduate School, Chinese Academy of Agricultural Sciences.

India: I. Vimal Jothi, Tamil Nadu Agricultural University; Wasim Iftikar, Visva Bharati University.

Latin America: Nahuel Reussi Calvo, National University of Mar del Plata, Argentina; Sebastian Mazzilli Vanzini, Universidad de Buenos Aires, Argentina.

Southeast Asia: Trinh Quang Khuong, Cuu Long Rice Research Institute (CLRRI),Vietnam.

Funding for the Scholar Award program is provided through support of member companies of IPNI, primary producers of nitrogen, phosphate, potash, and other fertilizers. Graduate students attending a degree-granting institution located in any country with an IPNI program region are eligible. Students in the disciplines of soil and plant sciences including agronomy, horticulture, ecology, soil fertility, soil chemistry, crop physiology, and other areas related to plant nutrition are encouraged to apply. Following is a brief summary of information for each of the 2008 winners.


Carolina Medina


Trenton Roberts

Ms. Carolina Medina is pursuing her Ph.D. degree at the University of Florida, with a doctorate dissertation titled "Towards Acceptance of a Short-Term Laboratory Test to Measure Nutrient Release Characteristics of Controlled-Release Fertilizers." Her research has been centered on developing methodologies to quantify the release properties of controlled-release fertilizer (CRF) sources.

Mr. Trenton Roberts is working toward his Ph.D. degree in the Department of Crop, Soil and Environmental Science at the University of Arkansas. His doctoral dissertation title is "Soil-Based Tests for Nitrogen Fertilizer Recommendations in Arkansas Rice and Wheat Production." His objectives include development of a soil-based N test that accurately quantifies potentially mineralizable N, total N uptake and relative grain yield with N fertilizer recommendations.


Darrin Roberts


Fernando Salvagiotti

Mr. Darrin Roberts is pursuing his Ph.D. degree in the Department of Agronomy and Horticulture at the University of Nebraska-Lincoln. His dissertation is entitled "An Integrated Crop- and Soil-Based Strategy for Variable Rate Nitrogen Management in Corn", with a focus on how to combat the potential environmental hazards of N fertilizer applied to fields. His study involves active canopy reflectance sensors as a tool to accurately assess N stress during the growing season.

Mr. Fernando Salvagiotti is completing his Ph.D. degree in the Department of Agronomy and Horticulture at the University of Nebraska-Lincoln. His thesis title is "Nitrogen Fixation in High Yielding Soybeans." The primary objective is to quantify the contribution of N fixation during the entire crop growth cycle under different N management strategies. A native of Argentina, Mr. Salvagotti is returning to Argentina to continue research and extension projects.


Mark Slavens


Amy Burton

Mr. Mark Slavens is pursuing a Ph.D. degree in Horticulture at Cornell University in Ithaca, New York. His thesis title is "Nutrient and Pesticide Fate in Home Lawns through Runoff and Leachate", and seeks to help homeowners, turfgrass managers, and others better assess use of fertilizers and pesticide products.

Ms. Amy Burton is working toward a Ph.D. degree in Horticulture at Pennsylvania State University. Her dissertation title is "Physiological Trade-Offs to Nutrient Uptake and Genetic Regulation of Aerenchymatous Root Tissue of *Zea mays*", with a focus on the formation of aerenchyma in the roots of maize (corn) and the role of this tissue in nutrient acquisition in crop plants. Aerenchyma is a tissue formed from root cortical cells in response to environmental factors which offers great potential for greater uptake and use efficiency of some nutrients.


Xiaofeng HU


Xiaokun LI

Ms. Xiaofeng HU is completing her Ph.D. degree at Southwest University in Chongqing, China, with a thesis title of "Effect of Slow Release Compound Fertilizers (SRCF) on Environment and Crops." The development of SRCF technology offers several potential advantages, including the opportunity to improve resource utilization, improve profitability, and reduce environmental concerns in China.

Mr. Xiaokun LI is completing his Ph.D. degree program at Huazhong Agricultural University in Wuhan, Hubei Province, China. His dissertation title is "Research on Two Kinds of Fish Grasses and Balanced Fertilization", and seeks to improve understanding of grasses produced for fresh water fish production. Working with sudangrass and rye grass, his study is showing the advantage of properly balanced applications of N, P, and K to increase forage yields.


Wenjuan LI


I. Vimal Jothi

Ms. Wenjuan LI is pursuing studies for a Ph.D. degree at the Chinese Academy of Agricultural Sciences (CAAS) with a thesis title of "Effect of Potassium on Sugar, Phenol Metabolism, and Its Relation to Corn Stalk Rot." Her study has found that when corn (maize) plants are infected by the stalk rot pathogen, they tend to absorb more K, which increases resistance.

Ms. I. Vimal Jothi has been involved in doctoral studies at Tamil Nadu Agricultural University (TNAU), India, for the past 2 years with the thesis title of "Effect of Neem-Coated Urea on Nitrogen Use Efficiency, Yield, and Quality of Sugarcane." Her study seeks to address the problem of storing more N in soils of arid and semi-arid regions, which is complicated by limitations to build-up of soil organic matter.


Wasim Iftikar


Nahuel Reussi Calvo

Mr. Wasim Iftikar is pursuing a Ph.D. degree in Agronomy through a program called "Studies on Geographic Information System (GIS)-Based Soil Fertility Mapping for Nutrient Management in Red and Lateritic Soils" at Visva Bharati University, India. Its objectives include assessment of spatial variability, comparing the relative efficiency of a GIS map-based soil fertility evaluation system to conventional soil testing for native fertility prediction in farmer fields, and exploring use of GIS maps in site-specific nutrient management in the rice-potato-sesame cropping sequence.

Mr. Nahuel Reussi Calvo is seeking his Ph.D. degree at the National University of Mar del Plata, Buenos Aires, Argentina. His dissertation title in "Sulphur Deficiency in Wheat: Indicators of Availability in Plant Tissue", and involves research to better understand sulphur nutrition and its relationship with N availability.


Sebastian Mazzilli Vanzini


Trinh Quang Khuong

Mr. Sebastian Mazzilli Vanzini is earning his Ph.D. degree at Universidad de Buenos Aires in Argentina with a dissertation title of "Tillage and Root Production and Distribution Importance in the Balance of Carbon in Cultivated Soils." A native of Paysandu, Uruguay, he graduated as Agronomist from Universidad de la Republica in 2005. As part of his Ph.D. program, he initiated a large long-term study at the Experiment Station of Facultad de Agronomia in Uruguay. His work addresses the impact of management on long-term carbon balance of soils.

Mr. Trinh Quang Khuong is working toward his Ph.D. in Agronomy at Can Tho University, Vietnam. His thesis is "Optimization of Integrated Crop Management (ICM) with Emphasis on Plant Population, Fertilizer N Management, and Water Regime under Different Cropping Systems in Intensive Rice Farming." He has worked previously for over 20 years in the Department of Agronomy of Cuu Long Rice Research Institute (CLRRI) and played an important role in national and international studies regarding fertilizer management and integrated crop management for rice and maize.

The IPNI Scholar Award recipients are selected by regional committees of IPNI scientific staff. The awards are presented directly to the students at their universities and no specific duties are required of them. More information is available from IPNI staff, from individual universities, or from the IPNI website: >www.ipni.net/awards<. BC

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

Fertilizing Irrigated Cotton for High Yield and High Nitrogen Use Efficiency

By Yan Zhang, Wei Hu, Yuan Gao,Yinkun Yao, Mingyao Tang, and Guozhi Hu

Nitrogen was the first limiting factor in a cotton production study in Xinjiang Province, followed by P and then K. Key considerations to maximum N recovery included a top-dress schedule able to sustain adequate N supply throughout flower initiation and boll formation as well as balanced quantities of P and K fertilizer.

Cotton production continues to be a leading industry for the northwestern province of Xinjiang and the crop remains a primary source of income for farmers. Most recent statistics indicate planted area at 1.7 million ha, accounting for 31% of China's total cotton area. Xinjiang's cotton yield and total production also ranks highest across all provinces in China. Nutrient management is an important consideration for cotton, but farmers typically overuse N fertilizer, while K application is not sufficient. Despite this knowledge, it has been unclear how imbalanced use of nutrients is affecting cotton production in Xinjiang.

Field experiments were conducted from 2001 to 2003 and 2006 to 2007 in Awati, Kuche, and Manasi counties of Xinjiang Province (**Table 1**). Plots were arranged in a randomized complete block design with three or four replicates. Awati and Kuche are located along the northern edge of the Takelamagan Desert, and Manasi is located to the north of Urumqi. These areas have abundant sunshine, intense evaporation, and little precipitation. Climatic conditions and the local infrastructure combine to make these areas well-suited to high quality cotton production.

All experiments tested an 'optimum' (OPT) treatment containing N, P, and K, as well as nutrient omission treatments including an OPT-N, OPT-P, OPT-K. Recommended N, P, and K rates in the OPT were based upon the Agro-Services International (ASI) method used by the National Laboratory of Soil Testing and Fertilizer Recommendations in Beijing (Portch and Hunter, 2002). From 2001 to 2003, experiments were located at Await and Kuche counties. Basal fertilization at these sites included all of the P and K recommendation plus 60% of the total N. The remaining N was applied at flower initiation stage before the first or second irrigation.

In 2006 and 2007, field experimentation at Awati and Manasi counties evolved to a more detailed investigation of the impacts of N, P, and K rates on yield, nutrient uptake, and N use efficiency. These experiments varied four rates of N, P, and K which were co-applied along with set rates for the other two nutrients. In 2006, basal fertilization included 30% of the total N recommendation plus all of the P and K. The remaining N was applied along with irrigation water in four topdressings applied at June 24 (15%), July 5 (25%), July 25 (20%), and August 12 (10%). In 2007, all of the P and K fertilizer was applied basally and N was applied along with irrigation as five topdressings at June 20 (15%), July 18 (35%), August 5 (25%), August 22 (20%), and September 2 (5%).

Table 1. Physical and chemical properties of tested soils by ASI procedure.

Year/Location	pH	O.M. %	Ca	Mg	K	N	P	S	B	Cu	Fe	Mn	Zn
			µg/ml										
2001 Awati	8.0	0.6	1,978	245	130	8	38	90	2	1	11	10	1
2002 Awati	7.8	0.5	7,621	141	104	7	9	124	0.1	1	3	6	1
2002 Kuche	8.5	0.3	1,305	257	278	16	32	39	2	2	15	12	1
2003 Awati	7.8	0.4	4,433	216	115	20	20	132	2	2	6	9	1
2006 Awati	8.6	0.3	782	549	172	1	31	184	3	3	34	10	2
2007 Manasi	8.6	0.7	2,005	499	114	70	17	69	1	3	16	6	1
Critical Values			401	122	78	–	12	12	0.2	1	12	2	1

A plant biomass and N accumulation study was also initiated in 2006 at Awati. Cotton plant (Xinhai-20 cv.) samples were taken on May 11 (seedling), June 11 (budding), June 28 (flowering), August 4 (bolling), and September 9 (batting). Stalk, foliage, bud and flower, hull of boll, fiber, and seed were collected and analyzed. Results determined a relatively slow rate of accumulation for both plant biomass and N up until flowering, after which the majority of accumulation took place (data not shown).

The mean proportion of total biomass at stages of seedling, budding, flowering, bolling, and batting was 1%, 6%, 21%, 51%, and 21%, respectively. Plant biomass responded to increased rates of N, P, and K throughout early crop development. The impact of fertilizer treatment on N accumulation was consistent with results observed for biomass. The mean proportion of total N accumulation at stages of seedling, budding, flowering, bolling, and batting was 2%, 10%, 25%,

Table 2. Effect of N, P, or K omission on cotton lint yield.

	2001 Awati	2002 Awati	2002 Kuche	2003 Awati	2006 Awati	2007 Manasi
	kg/ha					
OPT[1]	1,564a	1,503a	1,547a	1,462a	1,498a	1,687a
OPT-N	1,199b	1,092b	1,194d	1,092d	1,234c	1,435b
OPT-P	1,238b	1,233b	1,330c	1,239c	1,348b	1,454b
OPT-K	1,303b	1,274b	1,393b	1,345b	1,333b	1,539b

[1]OPT N-P_2O_5-K_2O rates were 207-138-50 for 2001, 207-138-72 for 2002 and 2003, 225-140-70 for 2006, and 180-105-60 for 2007.

Numbers followed by the same letter in columns are not significantly different at p=0.05.

Cotton varieties by year and location: 2001-2003 in Awati, Xinhai-16 cv.; 2002 in Kuche, Xinluzhong-9 cv.; 2006 in Awati , Xinhai-20 cv.; and 2007 in Manasi, Zhongmian-297-5 cv.

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

Table 3. Effect of N rates on N use efficiency.

Year/location	$N-P_2O_5-K_2O$	Lint yield of cotton, kg/ha	Net returns, US$/ha	Total N uptake, kg/ha	AE, kg/kg N	Recovery efficiency, %
2006 Awati	0-140-70	1,234 c	–	131	–	–
	112-140-70	1,361 b	309	149	1.1	16
	225-140-70	1,498 a	647	211	1.2	35
	338-140-70	1,413 ab	340	191	0.5	18
2007 Manasi	0-105-60	1,435 c	–	149	–	–
	90-105-60	1,541 b	153	163	1.2	16
	180-105-60	1,687 a	383	215	1.4	37
	270-105-60	1,510 bc	-4	202	0.3	20

For Tables 3 to 5, in 2006, the price of cotton lint (Xinhai-20 cv.) is 22 RMB/kg, N is 4 RMB/kg, P_2O_5 is 4 RMB/kg, K_2O (K_2SO_4) is 7 RMB/kg. In 2007, the price of cotton lint (Zhongmian-297-5 cv.) is 14 RMB/kg, N is 4 RMB/kg, P_2O_5 is 5.4 RMB/kg, K_2O (KCl) is 4 RMB/kg. 1US$=7.5 RMB. In each year, numbers followed by the same letter are not significantly different at p=0.05.

Table 4. Effect of P rates on N use efficiency.

Year/location	$N-P_2O_5-K_2O$	Lint yield of cotton, kg/ha	Net returns US$/ha	Total N uptake, kg/ha	Increase of N recovery efficiency, %
2006 Awati	225-0-70	1,348 b	–	147	–
	225-70-70	1,395 b	97	157	4
	225-140-70	1,498 a	358	211	28
	225-210-70	1,405 ab	48	198	22
2007 Manasi	180-0-60	1,454 b	–	150	–
	180-52-60	1,538 b	122	154	2
	180-105-60	1,687 a	369	215	36
	180-158-60	1,485 b	-54	165	8

Table 5. Effect of K rates on N use efficiency.

Year/location	$N-P_2O_5-K_2O$	Lint yield of cotton, kg/ha	Net returns US$/ha	Total N uptake, kg/ha	Increase of N recovery efficiency, %
2006 Awati	225-140-0	1,333 c	–	166	–
	225-140-35	1,354 bc	28	177	5
	225-140-70	1,498 a	414	211	20
	225-140-105	1,466 ab	289	185	9
2007 Manasi	180-105-0	1,539 b	–	162	–
	180-105-30	1,584 b	69	165	2
	180-105-60	1,687 a	249	215	29
	180-105-90	1,578 ab	24	173	6

40%, and 23%, respectively.

Five years of omission plot study determined N to be the most limiting nutrient factor in cotton yield in Xinjiang followed by P and then K (**Table 2**). Over all years, balanced use of N, P, and K significantly increased cotton lint yield by an average of 28%, 18%, and 13%, compared with the OPT-N, OPT-P, and OPT-K treatments, respectively.

The highest cotton lint yield and economic return, as determined by the final 2 years of study at Awati and Manasi, were obtained when 225 kg N/ha was applied along with 140-70 kg/ha of $P_2O_5-K_2O$ in Awati in 2006, and when 180 kg N/ha was combined with 105-60 kg/ha of $P_2O_5-K_2O$ in Manasi in 2007 (**Table 3**). Agronomic efficiency (AE) —calculated as lint yield increase per unit N and apparent recovery efficiency (RE)—calculated as the increase in N uptake per unit N added—were also highest under these same treatments (**Table 3**). These balanced NPK combinations resulted in AE values of 1.2 and 1.4 kg N/kg N, while RE was 35% and 37% in 2006 and 2007, respectively. Under the optimal fixed rates of N and K fertilizer, recovery of N increased by 28% under optimal P at Awati, and by 36% at Manasi (**Table 4**). Similarly, optimal K application allowed for 20% more N recovery at Awati and 29% more N recovery at Manasi (**Table 5**).

Balanced use of fertilizer nutrients is important for improved cotton yield and N use efficiency in Xinjiang. Soil testing used to evaluate soil nutrient supply provided good direction with regards to fertilizer nutrient application. Profits were highest with the N rates recommended, and balanced use of P and K were effective in supporting improved farmer profit and N recovery. Soil testing also provided the necessary guidance to avoid over-application of nutrients, a critical management practice in the effort to achieve optimum fertilizer best management practices. BC

Ms. Zhang is Professor, and Mr. W. Hu is Assistant Professor, Soil and Fertilizer Institute, Xinjiang Academy of Agricultural Sciences, Urumqi, 830091, China; e-mail: yzhang@ppi.caas.ac.cn. Ms. Gao, Mr. Yao, Mr. Tang, and Mr. G. Hu are postgraduate students, Natural Resource and Environment College, Xinjiang Agricultural University, Urumqi, 830052, China.

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New Methods for Managing Midseason Nitrogen in Rice

By Gene Stevens and David Dunn

Managing N fertilization in rice production is a challenge throughout the world. In the USA, a simple method is needed to aid farmers with midseason N decisions in dry-seeded, delayed flood rice. A fast, inexpensive technique called the "yardstick method" looks promising.

A standard rice N fertilization program in the North Mississippi River Delta area is 70 to 120 lb N/A as urea applied preflood at first tiller, followed by aerial application of 30 lb N/A at 0.5 in. internode elongation and 30 lb N/A applied one week later (Dunn and Stevens, 2006). Potential N losses from urea volatilization before flooding and denitrification after flooding may or may not occur. Depending on well pump capacity and land area, fields often take several days to flood after urea is broadcast. Extension recommendations for preflood N rates in rice are usually based on field calibration tests with adjustments for specific cultivars, crop rotation, and soil texture. In recent years, many farmers have begun using a single application of 100 to 150 lb N/A preflood to avoid the expense of aerial applications of N at midseason.

With these uncertainties and higher N fertilizer prices, rice producers have been looking for ways to more closely predict the need for applying N midseason. Traditionally, rice leaf color, tissue N content, and plant area measurements have been used to determine whether midseason N is needed on a rice field.

Currently, only a small number of rice farmers and crop consultants in the USA are using Minolta® SPAD chlorophyll meters for managing midseason N because of the purchase cost (>US$1,300 per SPAD meter) and the need to establish high N reference strips early in the season. By comparing readings to reference strips, farmers can avoid trying to "green up" rice that has other problems besides N deficiency. Scientists at the International Rice Research Institute (IRRI) in the Philippines developed a leaf color chart, which is a less costly method of detecting rice leaf green color intensity (Shukla et al., 2004). This tool is being used with good results around the world. However, the need to use high N reference strips also applies to this method. And for color blind individuals, matching a rice leaf to green color plates on a chart is not possible.

Plant area measurements with a rice gauge have also been used to predict midseason N need. Research showed that plant area values are a more reliable estimator of total plant N than leaf N concentrations and chlorophyll readings (Ntanatungiro et al., 1999). Although rice gauges have been widely promoted by extension specialists, very few consultants use them because of the labor required. A person must carry a clipboard and pencil to record numbers, slide and lock the trapezoid in place, prevent the vertical shaft from falling over in the mud while backing away to estimate height and width, and then move to another sample location in a field.

The "Yardstick Method"

To help farmers be sure that no additional midseason N is needed, we developed a fast, inexpensive field test called the "yardstick method". Experiments at Qulin and Portageville, Missouri (USA) showed that the method did a good job of predicting yield response to midseason N. Leaf canopy is estimated by counting the inch numerals visible on a yardstick floating between rice row drills. Yardsticks can be purchased for less than $5 and no calculations are needed to decide whether more N is needed.

Here is how a yardstick reading is collected:

- At green ring rice growth (R1) stage, float a wood or plastic yardstick between two 7.5-in. rice drill rows.
- Standing between adjacent rows and leaning over the sampling rows, count the inch numbers showing on the yardstick (not hidden by rice leaves) out of 36 numbers possible (**Figure 1**).
- When a rice leaf obstructs the view of one digit in a two-digit number to the point that the whole number is not recognized, do not count that number.
- Keep both eyes open during the readings. Stand straight and avoid looking around leaves by rotating your head to read numbers on the yardstick.

The number of sample locations in a rice field where measurements need to be taken depends on the uniformity of

Figure 1. Rice leaves blocking the overhead view of inch numbers on a yardstick floating in floodwater between rice drill rows. The count on this example would be 16 numbers showing.

Figure 2. Example digital images. Left to right: low preflood N to high preflood N, collected at R1 growth stage with a digital camera in rice plots. Values in the lower right corner of photos were the proportion of green pixels in images.

Abbreviations and notes for this article: N = nitrogen;

the field. Generally, it is best to take at least 10 measurements in a field.

Yardstick numbers showing are indicators of crop leaf canopy closure and can be influenced by leaf orientation. The rice varieties commonly grown in the North Mississippi River Delta region have been selected for vertical leaf orientation for the uppermost leaves. This change in leaf orientation improves light penetration into the canopy compared to the more horizontal leaf position of older cultivars. Yields are maximized in these rice varieties when leaf interception of available sunlight is maximized.

Table 1. Average rice yield response to midseason N applications (30 lb N/A at growth stage R1 followed by another 30 lb N/A 7d later) relative to visual number showing on yardstick at R1 growth stage for Francis and Cheniere varieties on Sharkey clay and Dewitt silt loam soils.

Yardstick numbers showing	Change in rice yield, lb/A
10	-392
12	-134
14	90
16	291
18	470
20	622
22	750
24	874
26	930
28	974
30	1008

Results

The yardstick method was evaluated with two rice varieties (Cheniere and Francis) over 3 years on clay and silt loam soils. No yield response was produced from midseason N (30 lb N/A at growth stage R1 followed by another 30 lb N/A 7d later) when fewer than 14 numbers were showing at green ring growth stage on a yardstick floating between drill rows (**Table 1**). The results showed that applying midseason N to rice that does not need it is not only wasteful, but often reduces yield.

We also evaluated the use of digital cameras to estimate rice plant area for making midseason N decisions. The major disadvantage of this method is the cost of the digital camera and computer software for scanning images. In our tests, a camera was mounted on a 5-foot rod held above the plot (**Figure 3**). The camera was positioned level with the soil surface and recorded a plot area of 30 by 45 in. A computer macro program developed at the University of Arkansas was used with Sigma Scan™ Pro 5.0 image software (Aspire Software International, Asburn, Virginia) to determine the percentage of green pixels in each photo (**Figure 2**).

Figure 3. Collecting a digital photo for percentage green pixel analysis.

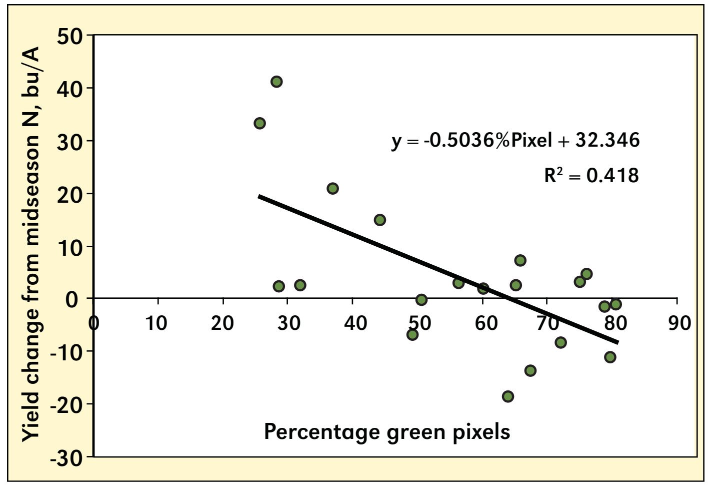

Figure 4. Rice yield response to midseason N applications relative to percentage of green pixels in digital images recorded at R1 stage from Francis and Cheniere varieties in 2005 and 2006 on Sharkey clay and 2006 on Dewitt silt loam soil.

No yield response was produced from midseason N when greater than 64% of the pixels were green color in digital images (**Figure 4**)

Both the yardstick and digital image methods of estimating yield response to mid-season N are specific to drill-seeded rice. It may be possible to use these methods in other rice production systems. However, before agronomic recommendations are considered, field evaluations should be conducted. For example, field calibrations would be required to determine critical levels for recommending midseason N on transplanted rice based on numbers showing on a meter stick or yardstick. BC

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Prediction of Available Soil Phosphorus Increases after Fertilization in Mollisols

By Gerardo Rubio, María J. Cabello, Flavio H. Gutiérrez Boem, and Eugenia Munaro

Accurate critical levels should be accompanied by predictive models on the amount of P required to increase P availability to a target value to obtain reliable P recommendations. Based on information on soil properties, we estimated the increase in soil available P after the addition of a unit of P, in pot studies, in an area of homogeneous though geographically distant loess-derived Mollisols of the Pampean Region in Argentina.

Reliable P fertilizer recommendations are needed for both economic and environmental reasons. They are usually based on the relationship between crop yield and soil P availability measured by specific soil tests (i.e. Bray 1, Olsen, Mehlich III). The soil test level separating deficiency and sufficiency is usually termed the critical level. At values below the critical level, P is assumed to be a constraint to crop yield and positive responses to P fertilization are expected. Plant species vary in P-critical levels, reflecting differences in crop demand, rooting patterns, and processes that lead to enhanced uptake.

In build-up and maintenance recommendation systems, critical levels must be accompanied by predictive models on the amount of P required to increase soil P concentration from an initial value to a target value (i.e. the agronomic or environmental critical level). These predictive models are much less abundant than the information referring to critical levels. Fertilizer requirement is largely dependent on the same chemical and physical characteristics of the soil that regulate P availability and sorption properties (Withers and Sharpley, 1995).

Most works studying the increase in available soil P after the addition of P have been developed using data sets including soils with extreme variation in one or more properties expected to strongly influence P response, as clay content (Cox, 1994), clay content and type (Quintero et al., 1999), or extractable aluminum (Haden et al., 2007). However, Beauchemin and Simard (1999) suggested that predictive models are best developed using homogeneous soils to account for their individual characteristics. Thus, current models may not be useful in areas with homogeneous soils, having small variability in clay and other basic soil characteristics. The large differences among soils may mask out the subtle differences that can be found in sets of homogeneous soils.

The soils of the Pampean Region (Argentina)–taxonomically similar, but distributed over a wide geographic area–can provide a data set that may allow an evaluation of the different soil characteristics that regulate the increase in available P. This region is the most productive agricultural area in Argentina and many of its soils are among the most fertile of the world. Cultivated Pampean soils are relatively homogeneous in terms of taxonomy and topsoil pH and clay content. The objective of this study was to estimate the increase in soil P availability after P additions under laboratory conditions, using information on soil properties.

Seventy-one soils were chosen from 31 representative agricultural areas of the Pampean Region (**Figure 1**). For the present study, 43 and 28 agricultural soils located North and South of the Flooding Pampa, respectively, were selected. All selected soils were non-calcareous, loess-derived Mollisols. Typic Argiudolls (26 soils) predominated among the Northern Pampean soils, followed by Typic Hapludolls (7); Entic Haplustolls (5), Thapto-Argic Hapludolls (4), and Abruptic Argiudolls (1). Typic Argiudolls (18) also predominated among the Southern soils, followed by Typic Haplustolls (5), Petrocalcic Paleudolls (3) and Thapto-Argic Hapludolls (2). Soils were sampled from the top 20 cm of the soil profile because that is the layer considered in local experiments for estimating P-critical levels for crops.

Soil samples were air dried, sieved to 2 mm and characterized for parameters related to soil P availability: pH, particle size distribution, organic C, total P, initial soil-available P, and P retention indices. In order to evaluate the sorption properties

Abbreviations and notes for this article: P = phosphorus; PRI-I = P retention index I; PRI-II = P retention index II; C = carbon; ppm = parts per million; h = hour.

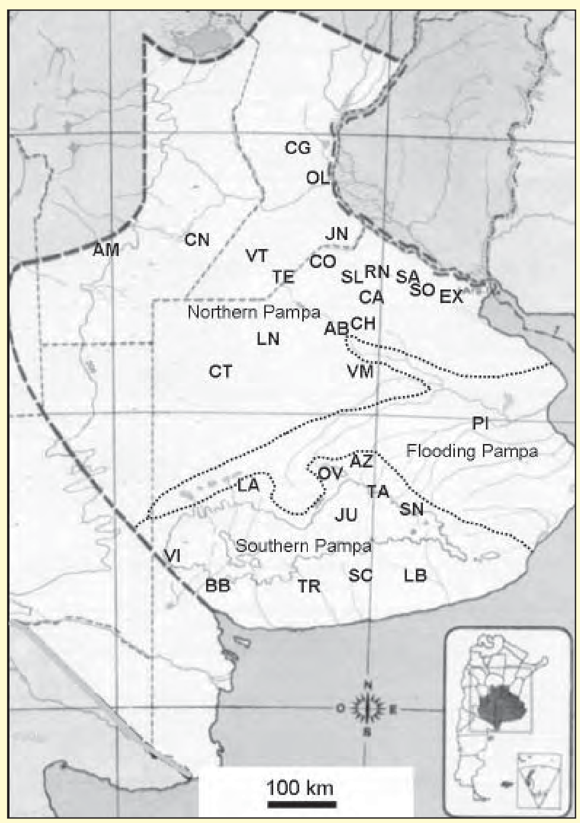

Figure 1. Sampling sites of the soils utilized in the present study. For each site, one to six soils were selected. Northern and Southern soils are those located above and below the straight line, respectively.

Table 1. Mean, minimum, maximum, and coefficient of variation values for the analyzed soil properties for 71 soils (whole dataset) and for the Northern (43) and Southern (28) soils.

	--- All soils ---		---------- North ----------				----------- South ----------				North vs. South
	Mean	CV[1]	Mean	Min.	Max.	CV	Mean	Min.	Max.	CV	p value[4]
b coefficient	0.52	22.5	0.58	0.33	0.74	13.6	0.41	0.27	0.58	19.9	***
Clay, g/kg	23.2	27.5	21.0	8.7	30	30.4	26.1	15.1	37.6	19.8	***
pH	6.1	6.1	6.0	5.3	6.9	4.8	6.4	5.9	7.5	6.4	***
Total C, g/kg	21.8	32.9	18.3	11.5	26.9	22.6	27.3	12.8	38.6	27.6	***
P Bray 1, mg/kg	12.1	64.7	11.2	2.4	30.3	65.2	13.7	3.3	35.6	63.0	NS
P total, mg/kg	324	19.8	299	211	359	12.8	362	191	490	21.1	***
PRI-I [2]	251	6.8	246	220	296	5.2	260	218	303	7.6	***
PRI-II [3]	310	12.6	289	242	336	7.1	343	275	418	11.3	***

[1] Coefficient of variation.
[2] P retention index I (Quintero et al. 1999).
[3] P retention index II (Sims 2000).
[4] p value for the t test comparing Northern and Southern soils: NS Not significant ($p > 0.05$), *** Significant at $p < 0.001$.

of the soil, two P retention indices were calculated: PRI-I was measured by the method proposed by Quintero et al. (1999), and PRI-II was measured following the method proposed by Sims (2000).

PRI-I consists of equilibrating 2.5 g of soil for 1 h with 25 ml of 0.1 M $CaCl_2$ containing 60 mg P/L at 25°C. Sorbed P was calculated as the difference between the P content in the added solution and the P content in the equilibrium solution. The PRI-I was then calculated as the amount of sorbed P divided by the logarithm to base 10 of the concentration of P measured in the equilibrium solution (Quintero et al., 1999). In order to calculate PRI-II, 1 g soil was equilibrated with 20 ml of 0.1 M $CaCl_2$ containing 75 mg P/L at 25ºC for 18 h. The other steps were similar to those described for PRI-I.

Soils were incubated in duplicate for 45 days with five levels of P (KH_2PO_4): 0, 8, 16, 32, and 64 mg P/kg soil in PVC pots containing 150 g soil. Pre-wetted soil samples were thoroughly mixed with a solution of KH_2PO_4. Potassium phosphate was used as it is the P source usually used in P sorption studies and has an intermediate behavior compared to triple superphosphate and diammonium phosphate, the fertilizer sources commonly used in the Pampean Region (Jiao et al., 2007, Schefe et al., 2007). After the incubation period, Bray P-1 was determined using a 1:7 soil to solution ratio and colorimetric P development.

The increase in available P, defined as the difference between available P for the P-enriched and the average of the two control pots, was calculated for each P level. Simple linear regressions of available P increase vs. added P were evaluated for each soil. The function used was $y = bx$, where y is the increase in available P, b is the slope, and x the P rate. In practical terms, the higher the b coefficient, the lower the amount of P necessary to reach a determined value of available soil P. In order to develop predictive models, regression analysis was used relating obtained b coefficients to different soil parameters. The variable *zone* was included taking into account the described ecological sub-regions of our study site. Values for this variable were 1 for soils north of the Flooding Pampa and 0 for Southern soils (**Figure 1**). The other variables included in the analysis were: clay, silt, and sand percentages, initial Bray P, total P, PRI-I, PRI–II, C content, and pH.

Predicting Soil P Increases

The main differences among Mollisols of the Pampean Region occur in the subsurface horizons. Most topsoil properties (e.g. clay content, pH) vary only slightly, with the exception of those characteristics affected by soil management, such as C content and nutrient availability. This was reflected in our measurements: total C and soil available P were the variables with the highest coefficient of variation (**Table 1**). Although in general terms the selected soils were homogeneous, soils from the Northern Pampa ecological sub-region (**Figure 1**) presented consistently lower clay content, total C, total P, pH, and P retention index values than soils located in the South (**Table 1**).

Values for the b coefficient can easily be converted to agronomic units (as the quantity of P in kg/ha to raise the soil test by 1 mg/kg) following the procedure shown in **Figure 2**. The relationship between the increase in available soil P and the amount of added P was linear and highly significant for each of the 71 analyzed soils (average $r^2 = 0.99$, minimum $r^2 = 0.94$). Thus, the b coefficient could be calculated directly from the slope of this relationship.

Obtained b coefficients ranged from 0.27 to 0.74, averaging 0.52 (**Table 1**). Southern soils had a significantly lower b coefficient than Northern soils. (**Table 1**) indicating that more P was needed to obtain a similar increase of available P in Southern soils. The b coefficient was negatively associated with the variable clay content, pH, total C, total P, and P retention indices, and positively related to Bray P-1. PRI–II was the best single independent variable for estimating b. As

Methodology is needed to calculate reliable P requirements to keep availability sufficient for maximum crop yields while avoiding environmental damage.

expected, the higher the P retention indices, the lower the coefficient *b*. Other measured properties associated with *b* were total C (r^2=0.31), PRI–I (r^2=0.30), clay (r^2=0.20), and pH (r^2=0.11). The majority of our soils fall in a very narrow range of pH values, which may explain the weak association observed between pH and *b*.

The best multiple regression model to predict the *b* coefficient (**Table 2**) included these variables: initial soil P, zone, and PRI–I (R^2 = 0.70). Because P retention indices and total P are not soil tests commonly provided by private or public laboratories, a second model excluding them was run (**Table 2**). This model retained a high coefficient of determination (R^2 = 0.61), and included these variables: clay content, initial soil P, and zone. A third model in which the zone variable was excluded and only measured soil variables were considered is also presented (**Table 2**). The variables selected by the model (R^2 = 0.62) were total P, initial soil P, pH, and P retention index II (**Table 2**).

Unlike previous studies that included more heterogeneous soils, initial P availability had an important role in predicting increases in soil available P due to P addition to the rather homogenous soils of the Pampean region. As expected, soil clay content and P retention indices also influenced the *b* coefficient. One of the main barriers to successfully mitigate the environmental damages caused by phosphates is the lack of precise estimation of the increase in available soil P due to the addition of P to soil, especially in agricultural areas of developing countries. Our information can strengthen P fertilization programs by providing a methodology to calculate reliable P requirements to keep P availability at a level sufficient for maximum crop yields while avoiding environmentally harmful excesses. Further research is needed to validate this method for other arrays of homogeneous soils that may differ in P dynamics. BC

Table 2. Multiple linear models for predicting *b* coefficient (n=71) according to Stepwise (R^2) methods. All models were significant at the 0.001 level.

	Equation	R^2
Model 1: all variables	0.95049 + 0.004826 Bray 1 P + 0.15450 Z[1] - 0.00233 PRI-I	0.70
Model 2: PRI and total P excluded	0.45369 + 0.00356 Bray 1 P + 0.16245 Z - 0.00344 Clay	0.61
Model 3: zone excluded	1.60087 + 0.00605 Bray 1 P - 0.08121 pH - 4.398E-04 total P - 0.00165 PRI-II	0.62

[1] Z is zone (0 for soils of the Southern Pampa and 1 for Northern soils).
Bray 1 P: extractable P (Bray 1). PRI-I: P retention index I. PRI-II: P retention index II.

In field crop ecosystems of Argentina, deficiencies of N, P, and S are frequently found.

Soil data

Top 20 cm:
P Bray: 11 mg/kg
Clay content: 28%
Bulk density: 1.2 t/m^3
Location: N Buenos Aires (Z = 1)

Estimation of b coefficient:

Coef b: 0.45369 + 0.00356 P Bray + 0.16245 Z - 0.00344 clay (%)
Coef b: 0.559

Objective of the fertilization

To reach P Bray: 15 mg/kg (topsoil 0 to 20 cm) It is necessary to increase 4 mg/kg P Bray (15 mg/kg to 11 mg/kg)

Phosphorus requirements to raise P Bray 1 ppm (kg P/ha) =

kg P/ha = 0.1 {Bulk density (t/m^3) x Deep (cm)}/Coef b
In our example
kg P/ha = {0.1 [1.2 (t/m^3) x 20 (cm)]/10}/0.559
kg P/ha = 24/0.559
kg P/ha = 4.29
It is required to raise 4 mg/kg P Bray 15 mg/kg - 11 mg/kg = 4 mg/kg. Fertilization rate: (4.29 kg/ha x 4) = 17.17 kg P/ha

Figure 2. Practical application of obtained results. The example from a field site located in the Northern Pampas. The farmer asked to raise the soil P test to 15 mg/kg, from an initial value of 11 mg/kg. Note: t/m^3 = metric ton per cubic meter.

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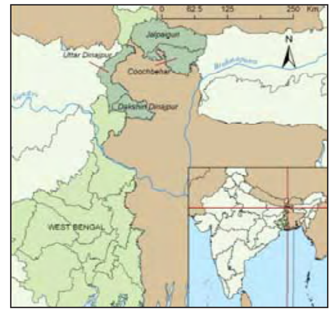
Response of Rainfed Rice to Soil Test-Based Nutrient Application in Terai Alluvial Soils

By D. Mukhopadhyay, K. Majumdar, R. Pati, and M.K. Mandal



Results of 2 years of field experiments evaluating the impact of soil test-based fertilization on rainfed rice showed significant yield increase with balanced use of nutrients. Omission of nutrients caused yield loss between 33 to 50% (- P), 20 to 32% (- K), 15 to 28% (- S), 33 to 35% (-Zn), and 31 to 34% (- B) in the Terai alluvial soils of West Bengal. Uptake of all the nutrients significantly correlated with yield, suggesting interdependence of nutrient uptake that influenced yield. Agronomic efficiency of P and K improved with 25% application of the nutrients over the optimum treatments. Recovery efficiency followed the same trend for all the nutrients studied.

Rice is one of the major crops in the northern districts of West Bengal. A little over 45% of the gross cropped area in the Terai alluvial zone of West Bengal is shared by Kharif (winter) rice. Existing statistics show that the productivity of rice in these districts…about 1.6 metric tons/hectare (t/ha) is considerably lower than the average productivity of 2.3 t/ha in the State. Uninterrupted rainfall during a part of monsoon months, occasional dry spells at flowering, a larger presence of local varieties in the field, and low level of fertilizer use are all reported to be important constraints to improved yields in the zone (Anonymous, 1989).

Soils of the Terai alluvial zone are typically deficient in several plant nutrients. Soil samples analyzed from the districts of Jalpaiguri, Coochbehar, Uttar Dinajpur, and Dakshin Dinajpur under Teesta-Terai alluvium showed that nearly 80% of soils fall under the low to medium category of N and K, while 60% of soils are low to medium in P (Ali, 2005). Availability of P and B are among the important nutrient related constraints in these soils. Soils of the Terai region are mostly acidic in reaction and contain high amounts of Fe and Al oxides and hydroxides. Fixation of applied P by such oxides and hydroxides is a common problem that hinders uptake of P by crops. Awareness about appropriate P application rates for rice in such soils among the farmers is critical to improve productivity. Deficiency of B in these soils is well recognized. Light textured soils and high rainfall (3,000 mm/year) in the region are contributing factors for B deficiency and most crops show distinct response to B application in these soils (Shukla et al., 1983; Saha, 1992). This zone of moderately leached coarse soils with poor fertility status offers scope to improve rice productivity through appropriate nutrient management. The present study was initiated to evaluate the effect of soil test-based fertilizer recommendation on winter rice and to identify the impact of nutrient omission from the recommended fertilizer schedule.

Researcher at rainfed rice plots.

The field experiments were conducted at the University farm, Pundibari, West Bengal, for two consecutive winter rice seasons. Random soil samples (0 to 15 cm) were collected from the experimental field, which remained fallow for the two previous years, before the start of the experiment for analysis following the Agro Services International (ASI) analytical methods (Portch and Hunter, 2002). Soils of the experimental plots were slightly acidic (pH 5.5 to 6.4) and sandy loam in texture with low status of the available N, P_2O_5, and K_2O (211, 11.4, and 95 kg/ha, respectively). The content of S (33.7 kg/ha) and Zn (1.25 kg/ha) was quite high in terms of the critical limit, while extractable B (0.28 kg/ha) was low in these experimental soils. A yield target-based recommendation was developed for rice cultivar IET-1444 (Khitish) following the ASI method. The experiment was laid out in a randomized block design with 12 treatments and four replications. The treatments were based on the full soil test-based fertilizer recommendation of 130 kg N, 100 kg P_2O_5, 100 kg K_2O, 35 kg S, 8 kg Zn, and 1.5 kg B per ha and was considered as optimum (OPT). The first six treatments included the optimum and subsequent omission of P, K, S, Zn, and B from the optimum rate. The second six treatments consisted of 125% of the OPT treatment where three major nutrients were applied at 25% higher than that of the optimum rate, keeping S, Zn, and B at the 100% level. The rest of the five treatments are omission treatments as described earlier. Uniform cultural practices and plant protection measures were used in all treatments. The basal fertilizer application included 25% of the total N and 100% of the P, K, S, Zn, and B. The first topdressing with 50% N was done 21 days after transplanting and the remaining N was applied at tillering stage. No organic amendments were applied prior to the sowing of the crop. Harvesting was done at maturity in the area marked in each plot, and treatment-wise yield and yield components were recorded.

The soil and plant samples at harvest were analyzed for nutrient concentration and uptake at maturity following standard procedures (Jackson, 1967), as were the residual soil nutrient content for each respective treatment.

Abbreviations and notes for this article: N = nitrogen; P = phosphorus; K = potassium; S = sulphur; Zn = zinc; B = boron; Fe = iron; Al = aluminum.

The average two season grain and straw yield of rice (Cv. Khitish) varied from 2,010 to 3,990 kg/ha and 4,390 to 8,000 kg/ha, respectively (**Table 1**). Maximum grain yield of rice was obtained at 125% of the optimum application rate. The straw yield was also highest in this treatment, followed closely by the 100% nutrient application. Omission of nutrients from the optimum treatment caused yield losses that varied between 20 to 35% (**Table 1**). Yield was strongly influenced by exclusion of Zn, B, and P that caused comparable yield losses (34%). Yield loss was much higher with omission of nutrients from the 125% OPT treatment and varied between 15 to 50%. Yield loss was highest in the OPT-P plot (50%), followed by more than 30% yield losses due to exclusion of Zn, K, and B from the OPT treatment. The yield data revealed that P, Zn, and B are the main limiting factors under the present experimental set up. Exclusion of nutrients from the optimum treatment did not influence the harvest index (**Table 1**).

Table 1. Effect of nutrients on grain and straw yield of rice, Pundibari, West Bengal.

Treatments	Grain yield, kg/ha	Straw yield, kg/ha	Δ Yield, kg/ha	Harvest index
OPT	3,760	7,690	–	0.33
OPT-P	2,530	5,310	1,230 (33)	0.32
OPT-K	3,010	6,140	750 (20)	0.33
OPT-S	2,710	5,950	1,050 (28)	0.31
OPT-Zn	2,450	5,120	1,310 (35)	0.32
OPT-B	2,490	4,760	1,270 (34)	0.34
125% OPT	3,990	8,000	–	0.33
125% OPT-P	2,010	4,390	1,980 (50)	0.31
125% OPT-K	2,700	5,450	1,290 (32)	0.33
125% OPT-S	3,380	7,030	610 (15)	0.33
125% OPT-Zn	2,680	5,710	1,310 (33)	0.32
125% OPT-B	2,750	5,880	1,240 (31)	0.32
CD (p=0.05)	18	10	–	–

Δ Yield = Yield of OPT- yield of omitted nutrient treatment; Data in parentheses are percent yield loss.

The average uptake of nutrients of rice (Cv. Khitish) varied from 74 to 130 kg/ha for N, 17 to 45 kg/ha for P_2O_5, 86 to 169 kg/ha for K_2O, 10 to 27 kg/ha for S, 5 to 18 kg/ha for Zn, and 0.02 to 0.08 kg/ha for B. The mean yield of rice for two seasons was significantly correlated with the uptake of all the nutrients (**Figure 1**). This suggests interdependence of uptake of a particular nutrient on the other applied nutrients, which ultimately influences yield. Such high correlation between yield and uptake of nutrients corroborates the importance of soil test-based nutrient application in kharif rice. The range and mean values for nutrient uptake per tonne of grain are provided in **Table 2**.

Table 2. Nutrient uptake expressed as kg/t of hybrid rice grain, Pundibari, West Bengal.

	N	P_2O_5	K_2O	S	Zn	B
Min	29.0	8.4	32.1	4.0	1.8	0.01
Max	38.9	12.5	46.5	8.0	4.5	0.02
Mean	34.3	9.9	39.8	6.0	3.0	0.01

Nutrient use efficiency can be expressed through agronomic efficiency (AE) and crop recovery efficiency (RE) (Fixen, 2005). Agronomic efficiency refers to the crop yield increase per unit of applied nutrient while recovery efficiency highlights the increase in plant nutrient uptake per unit of nutrient added. AE and RE were used in this experiment to assess the impact of soil test-based nutrient application and the effect of excluding nutrients from fertilization schedule (**Table 3**).

Table 3. Nutrient use efficiency of P, K, S, Zn, and B, Pundibari, West Bengal.

Parameters	Base treatment	P_2O_5	K_2O	S	Zn	B
Agronomic efficiency, kg/kg	OPT	12	8	30	164	850
	125% OPT	20	13	17	164	827
Recovery efficiency, %	OPT	24	52	19	49	2
	125% OPT	26	84	35	165	4

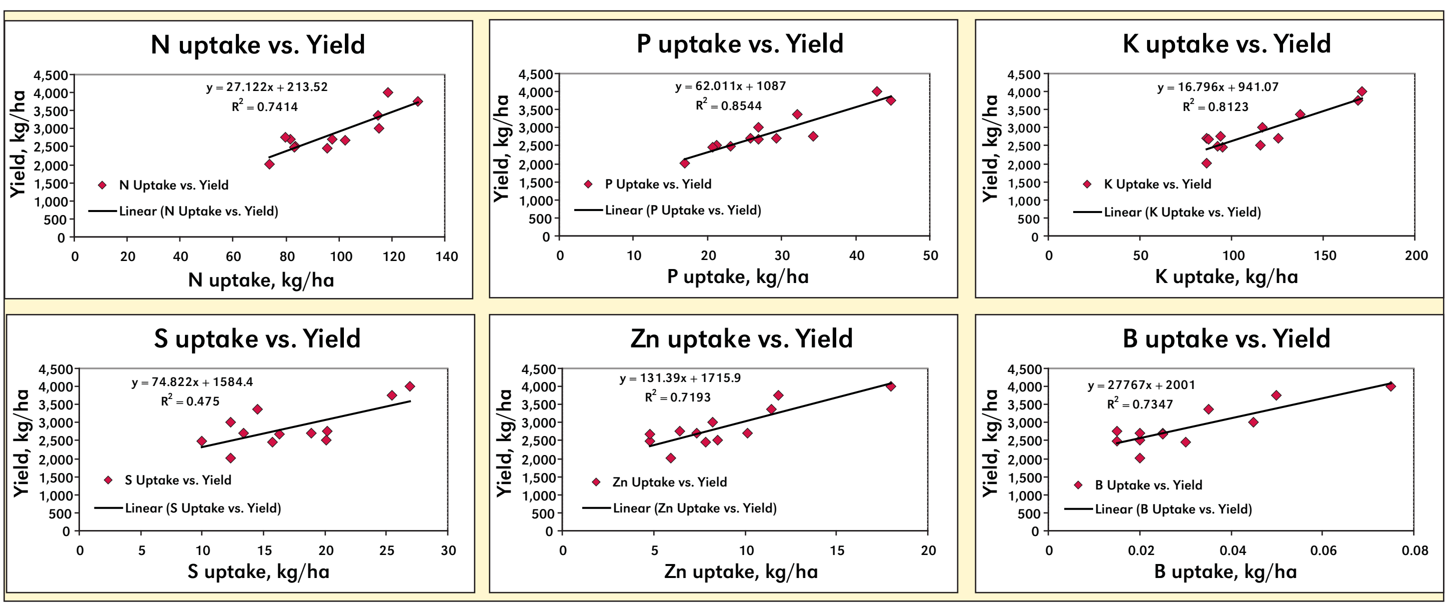


Figure 1. Interrelation between grain yield and uptake of nutrients in IET 1444, Pundibari, West Bengal.

Uptake of nutrients in plots correlated with yield, suggesting interdependence that influenced yield.

Both the efficiency parameters were compared with reference to the OPT and 125% OPT treatments. Agronomic efficiency of P and K improved with a 25% increase in application rates of these nutrients. Applying S at the 100% level, along with the 125% level of other macronutrient application rates, decreased the AE, while under a similar situation the AE of Zn and B remained unchanged. Recovery efficiency of all the nutrients increased considerably with the 125% OPT treatment.

From the results of the experiment, it was quite apparent that soil-test and yield target-based nutrient recommendation could help improve rainfed rice yield under the Terai alluvial situation of West Bengal. The experimental results showed that secondary (S) and micronutrients (B, Zn) had a significant influence on yield. This suggests that any productivity improvement effort in rainfed rice will need to take into account the effect of all limiting nutrients for a successful yield maximization program. Insufficiency of any of the studied nutrients in the fertilization schedule will cause considerable yield loss and subsequent loss of profit by the farmer. The best combination of nutrients for maximizing rainfed rice yield in the Terai alluvial situation is now being tested in farmers' fields to assess its effectiveness to improve yield and profit over traditional practices. BC

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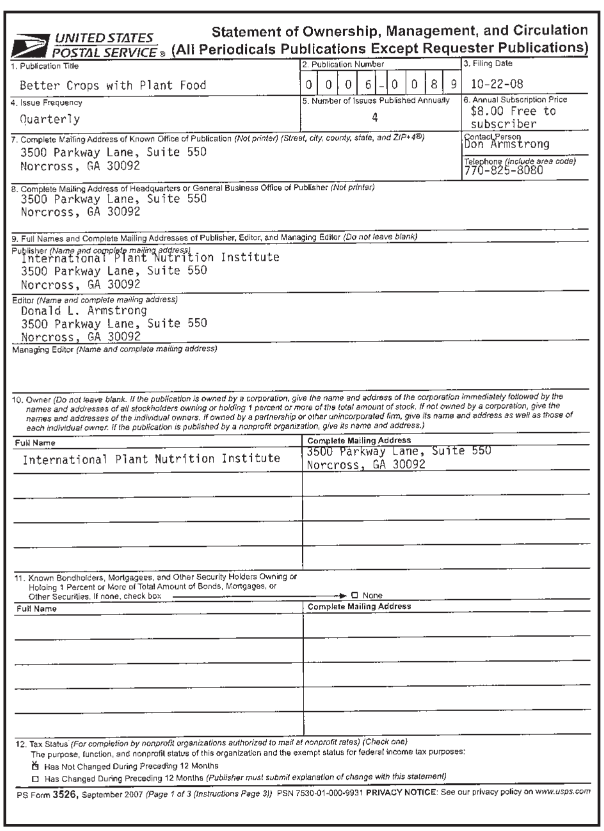

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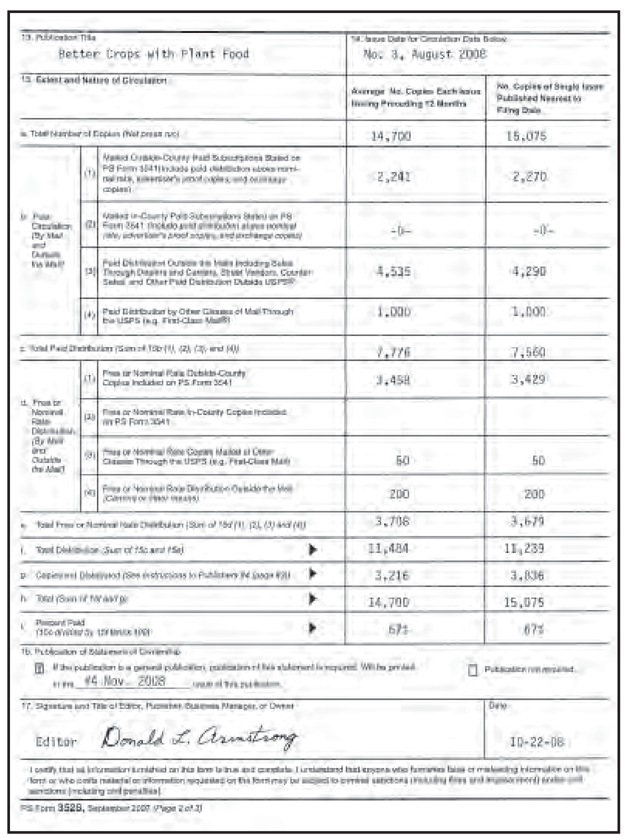

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Nitrogen Sources for Organic Crop Production

By Robert Mikkelsen and T.K. Hartz

Nitrogen is generally the most difficult nutrient to manage for organic crop production. Cover crops and composts can contribute substantial N for crops, but it is challenging to synchronize N release from these materials with the plant demand. Various commercial organic N fertilizers are available, but their costs may be prohibitive in many situations. Careful management of organic N sources is required to meet crop requirements, while avoiding undesirable N losses to the environment.

Nitrogen is the plant nutrient that is often most limiting to efficient and profitable crop production. Inadequate supply of available N frequently results in plants that have slow growth, depressed protein levels, poor yield of low quality produce, and inefficient water use. Nitrogen-stressed plants often have greater disease susceptibility compared with properly nourished plants. However, excessive N can be detrimental for crop growth and quality, in addition to causing undesirable environmental impacts. For these reasons, more research has been conducted on managing this plant nutrient than any other. This brief review does not address all the important aspects related to N management, but covers the major sources of N for organic crop production and their behavior in soil. An extensive list of references is available at this website: **>www.ipni.net/organic/references<**.

Although Earth's atmosphere contains 78% N gas (N_2), most organisms cannot directly use this resource due to the stability of the compound. Breaking the strong chemical bond in N_2 gas requires either the input of energy (to manufacture fertilizer) or specialized nitrogenase enzymes. Since the use of manufactured N fertilizer is not allowed for organic production, these materials are not specifically addressed here.

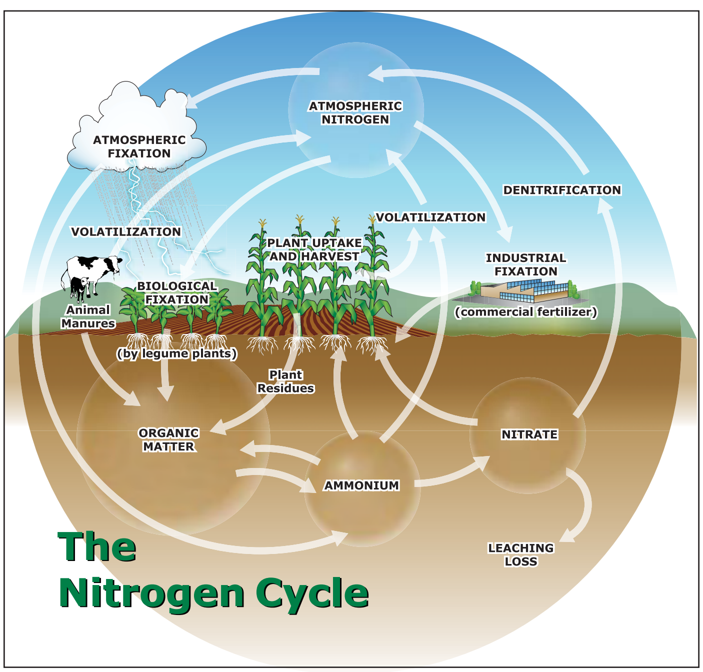

Figure 1. Where does the added N go? Organic N is converted to various inorganic N forms prior to plant uptake. Careful management reduces unwanted N loss to the environment.

Composts and manures can provide a valuable source of organic matter, but predicting the rate of N release to plants is not easy.

There are many biological and chemical processes that cause first-year recovery by plants to generally be less than 50% of the applied N. Low N efficiency can also be caused by imbalance of other essential plant nutrients. Management of N is also made difficult due to uncertainties related to weather events following fertilization. Where N recovery is low, it is important to consider where the unrecovered N may be going and the potential environmental and economic risks associated with these losses (**Figure 1**).

Almost all non-legume plants obtain N from the soil in the form of ammonium (NH_4^+) or nitrate (NO_3^-). Some organic N-containing compounds can be acquired by roots in small amounts, but these are not a major source of plant nutrition. Ammonium is the preferred inorganic source of N for some plants (especially grasses), but nitrification processes typically oxidize this N form to NO_3^-. Many other crops grow best with predominantly NO_3^- nutrition. In most warm, well-aerated soils, the NO_3^- concentration may be at least 10 times greater than the NH_4^+ concentration.

Unlike other plant nutrients (like P and K), there is no universal or widely used soil test to predict the amount of supplemental N required to meet the crop's need. Instead, the need for N supplementation is typically based on yield expectations, field history, and measurement of residual NO_3^-. Nutrients in commercial fertilizers are generally soluble, so their availability to plants is quite predictable. However, most organic N sources require mineralization (conversion to inorganic forms) before they can be used by plants. Environmental factors such as soil temperature, pH, moisture, and management practices such as tillage intensity all impact the rate of N availability from organic sources.

A major factor for using organic N sources involves knowing both the amount of N applied and the rate of N release from the

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

Table 1. First-year N availability coefficients for different manures and application methods (plant-available N).

Manure type	Soil incorporated	Surface applied	
		Broadcast	Irrigated
	Fraction of N available during the first year		
Poultry litter	0.6	0.5	–
Layer manure	0.6	0.4	–
Scraped swine manure	0.6	0.4	–
Scraped dairy manure	0.6	0.4	–
Swine lagoon effluent	0.8	0.5	0.5
Dairy lagoon effluent	0.8	0.5	0.5
Compost (C:N of 15:1 to 20:1)	0.05	0.03	
Compost (C:N >25:1)	0	0	

Source: Baldwin, K.R. and J.T. Greenfield. 2006. Composting on organic farms. http://www.cefs.ncsu.edu/PDFs/Organic Production - Composting.pdf
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Table 2. Major processes in the N Cycle.

Biological Fixation: Symbiotic relationship between bacterial rhizobia and a variety of leguminous plants allows dinitrogen gas (N_2) to be converted to plant-available forms of N. Some free-living bacteria and actinorhizal plants are also capable of biological N fixation. This is the major mechanism of supplying N in unfertilized soils.

Industrial Fixation: The process of combining atmospheric N_2 with hydrogen to form NH_3, the precursor to most other manufactured N fertilizers.

Ammonium Fixation: Certain clay minerals (such as mica, illite, and vermiculite) are capable of trapping NH_4^+ cations within the expanded clay layers. This phenomenon also can occur with K. The extent of this process varies considerable, from negligible to significant, depending on the clay mineralogy.

Immobilization: Immobilization occurs when soil microorganisms assimilate inorganic N, making it unavailable for plant uptake. The C:N ratio of added organic materials is a good, but not an absolute, predictor of whether N immobilization is likely (C:N ratio >25:1) or if mineralization is likely (C:N ratio <20:1).

Mineralization: The release of inorganic N from organic matter (proteins, amino sugars, and nucleic acids) following their decomposition by soil microorganisms. The rate of mineralization is influenced by numerous environmental and management factors, making it difficult to accurately predict in the field.

Nitrification: The 2-step bacterial oxidation of NH_4^+ to nitrite and then to NO_3^-. This process requires oxygen and is most rapid under conditions favorable for crop growth.

Denitrification: When oxygen is in short supply in the soil, many bacteria are capable of reducing NO_3^- to gases such as NO_2, N_2O and N_2. Denitrification results in a loss of plant available N and byproducts, such as N_2O, are potential greenhouse gases.

Volatilization: The loss of NH_3 from soil, compost, or manures is primarily a function of the chemical environment. In an alkaline environment, NH_4^+ changes to the gaseous NH_3 form and can be readily lost to the atmosphere from soil or organic materials. High temperatures and drying conditions also tend to speed the volatilization reactions, especially from NH_3-containing materials on the soil surface.

organic material. Nitrogen availability coefficients are used to estimate the fraction of total N that will be available for crop uptake during the first growing season (called *plant-available N* or PAN). The N availability coefficient can vary widely, based on the nature of the material, management practices (such as placement), and environmental factors (such as season of the year). Examples of PAN coefficients are shown in **Table 1**. Major processes of the N cycle are described in **Table 2**.

Mineralization of Organic Matter

When the crop's N supply comes exclusively from sources such as soil organic matter, cover crops, and composts, a thorough understanding of mineralization is essential to avoid a deficiency or surplus of available N. Mineralization is not consistent through the year and crop N demand should be matched with nutrient release from mineralization. Mineralization rates are dependent on environmental factors (such as temperature and soil moisture), the properties of the organic material (such as C:N ratio, lignin content), and placement of the material. Many excellent references discuss this process in detail.

Failure to synchronize N mineralization with crop uptake can lead to plant nutrient deficiencies, excessive soil N beyond the growing season, and the potential for excessive NO_3^- leaching (**Figure 2**).

Composts: Generally, composts contain relatively low concentrations of N, P, and K. They typically decompose slowly and behave as a slow-release source of N over many months or years since the rapidly decomposable compounds have been previously degraded during the composting process. Composts can be made from on-farm materials, but they are also widely available from municipal and commercial sources.

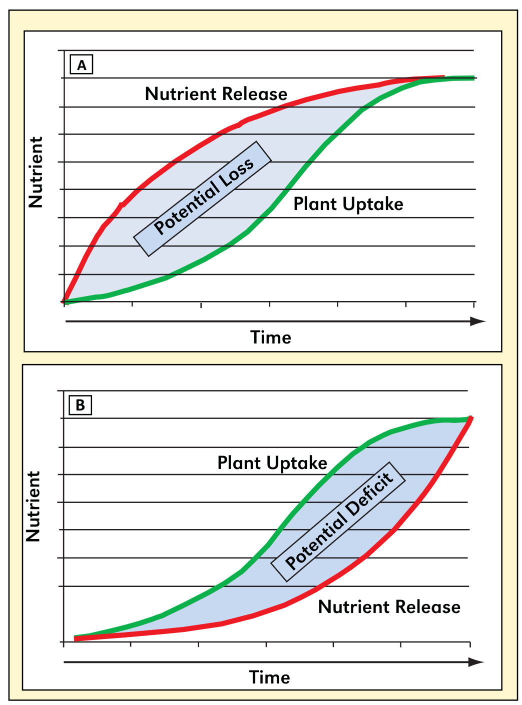

Figure 2. Synchronizing nutrient release with plant demand is a challenge with organic materials. Rapid release from organic sources with a low C:N ratio may supply nutrients more rapidly than the plant's demand (A). An organic material with a high C:N ratio may not release nutrients sufficiently rapid to meet the need of growing plants (B).

These composts vary in quality and tend to have low immediate nutritional value, but provide valuable sources of stable organic matter. Since plastic, trash, and industrial waste may also turn up in selected municipal composts, some organic certification programs do not allow their use. Commercially composted manure is widely available from a variety of primary organic materials.

Manure: The chemical, physical, and biological properties of fresh manure vary tremendously due to specific animal feeding and manure management practices. The manure N is present in both organic and inorganic forms. Nitrogen is unstable in fresh manure because ammonia (NH_3) can be readily lost through volatilization. Application of fresh manure or slurry on the soil surface can result in volatilization losses as high as 50% of the total N in some situations. The combination of wet organic matter and NO_3^- in some manure can also facilitate significant denitrification losses. The organic N-containing compounds in manure become available for plant uptake following mineralization by soil microorganisms, while the inorganic N fraction is immediately available. **Figure 3** shows the wide range in N mineralization of manure applied to soil.

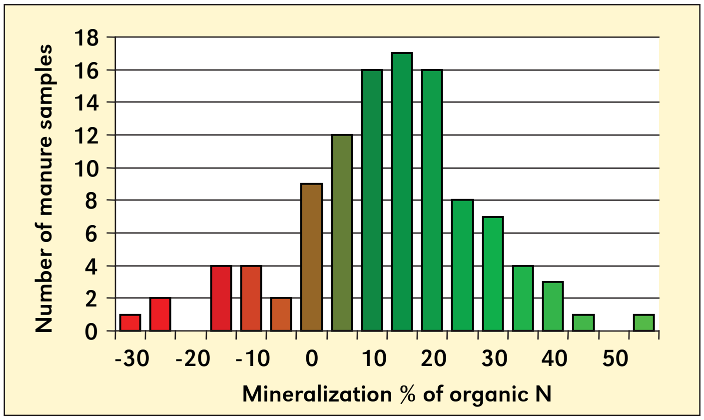

Figure 3. Nitrogen mineralization from 107 individual dairy manure samples after 8 weeks of incubation. On average, 13% of the organic N was mineralized, but 19 samples had net immobilization. Net N mineralization from the remaining 88 samples ranged from zero to 55%. (from Van Kessel and Reeves, 2002).

Determining the correct application rate of manure and compost to supply adequate PAN during the growing season can be difficult. Begin by having manures and composts regularly analyzed for nutrient content since there is considerable variability. The PAN will always be smaller than the total N in the manure since some loss occurs through volatilization with spreading, and only a portion of the organic N will be available to the plants during the growing season following application. The remaining organic N will slowly mineralize in later years.

When manures and composts are applied at the rate to meet the N requirement of crops, the amount of P and K added is generally in excess of plant requirement. Over time, P can build up to concentrations that can pose an environmental risk since runoff from P-enriched fields can stimulate the growth of undesirable organisms in surface water. Excessive soil K can cause nutrient imbalances, especially in forages. The long-term use of P and K-enriched manures to provide the major source of N must be monitored to avoid these problems.

Manures and composts can be challenging to uniformly apply to the field due to their bulky nature and inherent variability. Application of raw manure may bring up concerns related to food safety, such as potential pathogens, hormones, and medications. The use of raw manure is restricted for some organic uses and growers should check with the certifying agency before using.

Cover Crops: A wide variety of plant species (most commonly grasses and legumes) are planted during the period between cash crops or in the inter-row space in orchards and vineyards. They can help reduce soil erosion, reduce soil NO_3^- leaching, and contribute organic matter and nutrients to subsequent crops after they decompose. Leguminous cover crops will also supply additional N through biological N_2 fixation. The amount of N contained in a cover crop depends on the plant species, the stage of growth, soil factors, and the effectiveness of the rhizobial association. Leguminous cover crops commonly contain between 50 and 200 lb N/A in their biomass.

Cover crops require mineralization before N becomes plant available. The rate of N mineralization is determined by a variety of factors, including the composition of the crop (such as the C:N ratio and lignin content) and the environment (such as the soil temperature and moisture). As with other organic N sources, it can be a challenge to match the N mineralization from the cover crop to the nutritional requirement of the cash crop. It is sometimes necessary to add supplemental N to crops following cover crops to prevent temporary N deficiency.

Commercial Organic Fertilizers

Plant Products

Alfalfa meal (4% N), **cottonseed meal** (6% N), **corn gluten** (9% N), and **soybean meal** (7% N) are all examples of plant products that are sometimes used as N sources for organic production. These products are also used as protein-rich animal feeds. They require microbial mineralization before the N is available for crop uptake. Mineralization of these N-rich materials is generally rapid.

Alfalfa pellets.

Animal Byproducts

Blood Meal: Derived from slaughterhouse waste (generally cattle), dried powdered blood contains approximately 12% N and rapidly mineralizes to plant-available forms. It is completely soluble and suitable for distribution through irrigation systems.

Guano: Seabird guano (8 to 12% N) is derived from natural deposits of excrement and remains of birds living along extremely arid sea coasts. Guano was historically a very important N source before industrial processes for making fertilizer were developed. Many of the major guano deposits are now exhausted. Guano is also harvested from caves where large bat populations roost. It can be applied directly to soil or dissolved in water to make a liquid fertilizer.

Bat guano.

Feather Meal: Feather meal (14 to 16% N), a by-

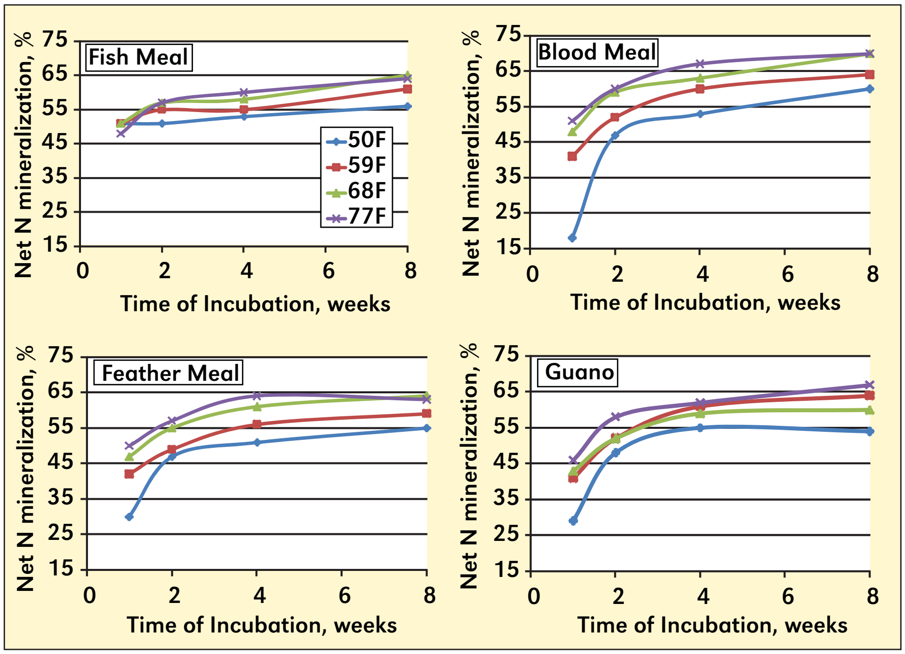

Figure 4. Nitrogen mineralization of four common organic N fertilizers at four soil temperatures. Mineralization of N expressed as percent of added organic N. Source Hartz and Johnstone, 2006.

product of the poultry industry, contains as much as 70 to 90% protein. It is mostly present as non-soluble keratin stabilized by highly resistant disulfide bonds. When treated with pressurized steam and animal-derived enzymes, the feather-based protein becomes a good source of available N for crop nutrition. Much of the feather N is not initially soluble, but it mineralizes relatively quickly under conditions favorable for plant growth. Pelletizing the feather meal makes handling and application more convenient. Unprocessed feathers usually have a delayed N release, but can also be an excellent N source if the difficulty in uniformly applying low density feathers to the soil can be overcome.

Fish Meal and Fish Emulsion: Non-edible fish (such as menhaden) are cooked and pressed to separate the solid and liquid fractions. The solids are used as fish meal (10 to 14% N) for fertilizer and animal feed. The valuable fish oil is removed from the liquid fraction and the remaining solution is thickened into fish emulsion (2 to 5% N). Additional processing is often performed to prevent premature decomposition. The odor from fish meal products may be unpleasant in a closed environment such as a greenhouse. Mineralization of fish-based products is generally rapid. Fish products that are fortified with urea to boost the N concentration are not allowed for organic production.

These high-N animal byproducts have relatively rapid N mineralization. At typical summer soil temperatures, more than half of the organic N may mineralize within 2 weeks of application (**Figure 4**).

Seaweed Fertilizers

Seaweed-based products are typically derived from kelp species (Ascophyllum). Dried kelp contains approximately 1% N and 2% K, with small amounts of other plant nutrients. Due to their low nutritive content, kelp products are generally used in high-value cropping situations where economics may be favorable, or for reasons other than plant nutrition.

Sodium Nitrate

Sodium nitrate ($NaNO_3$, 16% N) is mined from naturally occurring deposits in Chile and Peru, the location of the driest desert on earth where NO_3^- salts accumulate over time. Sodium nitrate is generally granulated and readily soluble when added to soil. The intended use of $NaNO_3$ in organic agriculture is typically to meet the N demand during critical plant growth stages and not to meet the entire nutritional need of the crop. In the U.S.A., the use of $NaNO_3$ is limited to no more than 20% of the crop N requirement. In some countries, the use of $NaNO_3$ is restricted.

Summing Up

Choosing the "best" source of N for organic crop production is difficult since nutrient ratios, PAN, mineralization rates, local access, ease of application, and cost all need to be considered. Computer-based tools are available to help with these choices. For example, Oregon State University has an "Organic Fertilizer Calculator" program that allows comparison of various materials to best meet the fertility needs of a soil. Similar programs are also available elsewhere.

Each organic N source has unique characteristics that require special management to gain the most benefit for plant health and economic production, while minimizing undesirable environmental losses. Commercial organic sources tend to be more costly to purchase than inorganic N sources, but many local or on-farm N sources may also be available. Some locally available N sources may contain low concentrations of N, requiring transportation and handling of large volumes of material. Cover crops are useful, but may be problematic to fit into a specific cropping system, depending on the length of growing season and rotational practices. As our understanding of soil N and organic matter improves, better N management will benefit all crop producers and the environment. BC

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For additional references, visit: >www.ipni.net/organic/references<.

Nitrogen Use Efficiency of Cotton Varies with Irrigation System

By Kevin F. Bronson

Nitrogen use efficiency is generally accepted to be less than 50% for field crops. West Texas is the largest contiguous cotton producing area in the world, with 4 million acres planted annually. Record high N fertilizer prices require better understanding of N use efficiency. Field research from 2000 to 2007 revealed that recovery efficiency of added N fertilizer ranged from a minimum of 12% in furrow irrigated fields to a maximum of 75% in subsurface irrigated, fertigated fields. Regardless of cotton variety or irrigation system, 40 lb of N in the cotton plant was required per bale (480 lb) of lint production.

West Texas plants 4 million acres of cotton yearly within a 100 mile radius of Lubbock (National Agricultural Statistics Service, 2004). Half of this acreage is dryland. About 70% of the irrigated land is center pivot, 25% is furrow-irrigated, and 5% is in subsurface drip irrigation. Nitrogen is the second constraint to this semiarid cotton production after water (Morrow and Krieg, 1990; Bronson et al., 2006). Nitrogen use efficiency will vary depending on how efficient the irrigation system is. The price of N fertilizer has escalated over the past few years resulting in increased interest in improving N efficiency. Understanding how N use efficiency changes from one irrigation mode to another will assist producers in N management decisions that affect profitability and N impact on the environment.

Since 2000, we have routinely analyzed cotton plants for total N uptake at first open boll in our N fertilizer management field studies. Nitrogen uptake is maximum at first open boll, after which N is lost as leaves drop (Li et al., 2001). We also measured N concentration of seed after harvest and ginning. In this paper, we analyze and summarize N uptake and yield data from over 200 plots between 2000 and 2007. We focused on zero-N plots and plots where N fertilizer rates were between 60 and 100 lb N/A. Where there was no statistical difference between N-fertilized and zero-N plots, the data were excluded.

There are several types of N use efficiency measures. The most common is recovery efficiency (Dilz, 1988).

$$\text{Recovery efficiency} = \frac{\text{TNU\_f} - \text{TNU\_0}}{\text{N fertilizer rate}}$$

Where TNU_F is total N uptake of N-fertilized plots and TNU_0 is total N uptake of zero-N plots.

Agronomic efficiency was calculated by Novoa and Loomis (1981).

$$\text{Agronomic efficiency} = \frac{\text{Lint yield\_f} - \text{Lint yield\_0}}{\text{N fertilizer rate}}$$

Where Lint yield_F is lint yield of N-fertilized plots and Lint yield_0 is lint yield of zero-N plots.

Internal N use efficiency was calculated by Witt et al., (1999).

$$\text{Internal efficiency} = \frac{\text{Lint yield\_f}}{\text{TNU\_f}}$$

Abbreviations and notes for this article: N = nitrogen; NO_3^- = nitrate;

The Southern Plains of Texas contains the largest contiguous cotton production in the world. About half of this production is irrigated.

Physiological efficiency was calculated by Isfan (1990).

$$\text{Physiological efficiency} = \frac{\text{Lint yield\_f} - \text{Lint yield\_0}}{\text{TNU\_f} - \text{TNU\_0}}$$

Urea ammonium nitrate (UAN, 32-0-0) was the N source used in all the studies. Nitrogen fertilizer was knifed-in or spoke-wheel applied 5 in. off the row and 4 in. deep at early squaring in the furrow irrigation studies (Booker et al., 2007). In the low energy precision (LEPA) studies, N was spoke-wheel applied the same way, except it was applied in two splits: one at first squaring and one at first bloom (Bronson et al., 2006). In the 2000-2002 surface and subsurface drip irrigation studies, N was applied in 30 lb/A doses at first square, early bloom, and mid bloom at the emitter during irrigation to simulate fertigation (Chua et al., 2003). In the subsurface drip studies from 2005 to 2007, N was injected into the system from 24 to 30 days between first square and mid bloom (Yabaji et al., 2009). Nitrogen fertilizer rates were based on yield goals (1.5, 2, and 2.5 bales/A for furrow, center-pivot, and drip tape irrigation, respectively) and 0 to 24 in. pre-plant soil test NO_3^- (Chua et al., 2003; Bronson et al., 2006; Booker et al., 2007; Yabaji et al., 2009).

Furrow irrigation consisted of four, 2 in. irrigations on every other furrow. Center pivot irrigation was configured with drop socks in every other furrow or LEPA irrigation (Lyle and Bordovsky, 1981). Irrigation in LEPA was every 2.5 days. Water was supplied through the surface drip system at 1.7 gal/hour every 3 days at 10 psi pressure. There were also furrow dikes in the surface tape furrows. Thus, in effect, this irrigation system

Table 1. Nitrogen use efficiencies, first open boll N accumulation, seed N uptake, and lint yields as affected by water management, Lubbock, Texas, 2000-2007.

Year	Irrigation	N fertilizer rate	Seed N uptake	Total N uptake	Seed N Recovery efficiency	Total N Recovery efficiency	Internal N use efficiency	Physiol. use efficiency	Agronom. use efficiency	Plus-N lint yield	Zero-N lint yield	N application details[4]
		------- lb N/A -------			------- % -------		--------- lb lint/lb N ---------			------ lb/A- -----		
2000	Subsurface drip	90	52	76	17	18	11.7	6.5	1.2	887	783	3, 30 lb N/A doses
2000	Surface drip tape	60	55	77	12	25	12.2	9.3	2.3	941	801	2, 30 lb N/A doses
2001	Subsurface drip	90	77	99	34	38	12.5	5.6	2.1	1,234	1,044	3, 30 lb N/A doses
2001	Surface drip tape	90	80	99	35	41	12.7	6.1	2.5	1,258	1,034	3, 30 lb N/A doses
2002	Surface drip tape	90	–	96	–	40	12.8	7.3	2.3	1,227	1,016	3, 30 lb N/A doses
2002	Furrow	70	62	–	17	24[1]	12.7[1]	5.7	1.3	1,124	1,027	Sidedress
2003	Furrow	77	39	–	8	12[1]	12.0	5.7	0.74	666	609	Sidedress
2003	LEPA	87[2]	54	–	11	16[1]	11.8	4.9	0.68	910	851	2, 45 lb N/A
2004	LEPA	85[2]	71	–	24	33[1]	11.5	5.6	2.2	1,162	975	2, 45 lb N/A
2005	Subsurface drip	90	97	160	34	63	11.3	3.4	2.1	1,812	1,620	30 fertigations
2005	Subsurface drip	65[3]	91	143	38	62	12.7	4.9	3.0	1,817	1,620	30 fertigations
2006	Subsurface drip	100	72	120	30	75	12.9	5.5	4.1	1,547	1,140	34 fertigations
2006	Subsurface drip	85[3]	66	107	35	71	13.3	4.7	3.4	1,427	1,140	34 fertigations
2007	Subsurface drip	80	75	128	28	65	10.4	6.0	3.2	1,326	1,068	24 fertigations
2007	Subsurface drip	62[3]	78	120	40	72	11.4	8.5	4.9	1,372	1,068	24 fertigations

[1]Assumes seed N uptake is 70% of total N uptake.
[2]Average variable-rate.
[3]Reflectance-based.
[4]Drip irrigation N applied between first square and mid bloom; sidedress N applied at first square; knifed-in treatments (LEPA) applied at first square and first bloom.

was very similar to LEPA. In the subsurface (12 in. depth) drip system, water flowed daily at 0.25 gal/hour at 15 psi pressure. Target amounts of irrigation in all systems except furrow was 85% estimated evapotranspiration replacement.

Seed N uptake of mature cotton was about 70% of total N uptake at first open boll (**Table 1**). We used this factor to calculate total N uptake in plots without total N uptake data. Lint yields generally increased in the order: furrow < LEPA < subsurface drip. A noteworthy factor affecting yield was that high–yielding picker cotton varieties were used in 2005 and 2006, with stripper varieties in all other years. Cotton was planted relatively late, i.e. late May to early June in 2000, 2003, and 2007. Early May is the optimum cotton planting time in West Texas.

Recovery efficiency varied from 12% in a furrow-irrigated field in 2003 to 75% in a subsurface drip irrigated field in 2006 (**Table 1**). Clearly, the more efficient irrigation systems had greater N recovery efficiency. This was due in part to more efficient N delivery, e.g. several splits, injection. Most reported N recovery efficiencies for cotton are <50% (Boquet and Breitenbeck, 2000; Rochester et al., 1997). Subsurface drip irrigations with frequent fertigations was clearly the most N fertilizer-efficient system. It also had the greatest zero-N plot yields among the irrigation systems. Yabaji et al. (2009) also reported low residual soil NO_3^-, leaching below 3 ft. and low denitrification in subsurface drip irrigated cotton. Subsurface drip irrigation is about double the per acre cost of a center pivot, but is rapidly replacing furrow irrigation systems in West Texas. Nitrogen is usually injected in 30 lb N/A doses through center pivots in West Texas, a system we were not able to test. The N recovery of this system probably approaches the 40% recovery, similar to what we achieved by applying

30 lb N/A doses in the surface tape system in 2001-2002. The task then is to further increase water use and N fertilizer use efficiency in center pivot and furrow irrigated cotton. Stabilized or slow-release N products may have potential to increase N use efficiency in furrow-irrigated cotton. Pre-plant soil testing of NO_3^- to 24 in. can greatly improve N fertilizer recommendations and N use efficiency for the western cotton belt.

Internal N use efficiency was remarkably similar for all irrigation systems, averaging 12 lb lint/lb N in the plant. This is illustrated in a plot of total N uptake vs. lint yield in bales (**Figure 1**). The slope of the regression line is 40 lb N/bale, which is a very efficient internal N use efficiency. This compares to 100 lb N/bale in Alabama (Mullins and Burmester, 1990) and 50 lb N/bale in California (Bassett et al., 1970).

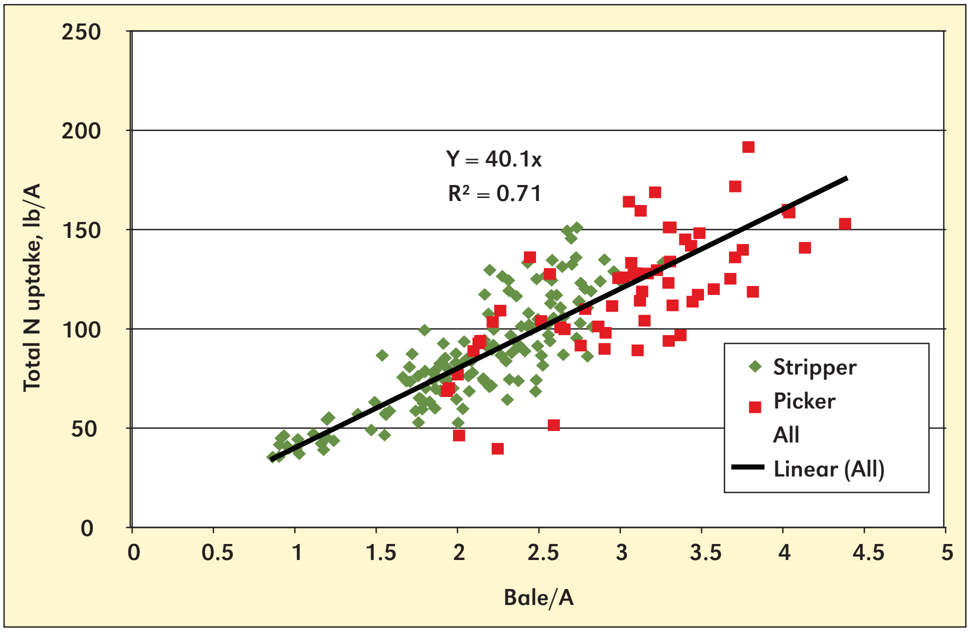

Figure 1. Total N uptake vs. cotton lint yields, West Texas, 2000-2007.

Physiological efficiency of N was more variable than internal efficiency, because it incorporates N response (**Table 1**). However, no real trends with irrigation systems could be observed. Agronomic N use efficiency is the most important to producers. Subsurface drip irrigation with fertigation (2005-2007) had the greatest agronomic efficiencies, while furrow and LEPA irrigations had the lowest.

Summary

Nitrogen fertilizer recovery in cotton ranged from 12 to 75% for furrow and subsurface drip irrigation systems, respectively. Nitrogen fertilizer in furrow-irrigated fields was sidedressesed in one dose at first square. In subsurface drip irrigation, low, frequent doses of N were fertigated between squaring and mid bloom. Recovery efficiency for surface drip tape that is similar to LEPA irrigation was 40%. Stabilized or slow-release N products may increase N use efficiency in furrow-irrigated cotton, although such products were not evaluated here. Internal N use efficiency was not affected by irrigation system and averaged 40 lb lint/bale. Pre-plant soil testing of NO_3^- to 24 in. can help improve N use efficiency in all irrigation systems, increase cotton growers' profits, and reduce export of N to soil, water, and air. BC

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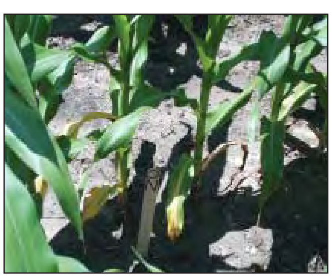
Crop Nutrient Deficiency Photo Contest Entries Due



Nitrogen deficiency in corn.

December 15, 2008, is the deadline for entries in the annual IPNI contest for photos showing nutrient deficiencies in crops. There are four categories: N,P, K, and Other. Supporting-information and verification data are required with original photos, preferably from the current year. Cash prizes are offered in each of the four categories: First place = US$150; Second place = US$75; and Third place, US$50. Entries can only be submitted electronically. For details and instructions, visit this website: >**www.ipni.net/photocontest**<. BC

IPNI Staff Members Honored at ASA/CSSA/SSSA Annual Meetings

Two IPNI staff members were recognized with awards at the recent annual meetings of the American Society of Agronomy (ASA), Crop Science Society of America (CSSA), and Soil Science Society of America (SSSA).

Dr. Harold F. Reetz, Jr., IPNI Director of External Support and FAR, received the Agronomic Service Award. The focus of the award is on agronomic service with associated educational, public relations, and administrative contributions of industrial agronomists, governmental, industrial, or university administrators, and others. Dr. Reetz received his B.S. degree at the University of Illinois and his M.S. and Ph.D. in crop physiology and ecology from Purdue University. A leader in the implementation of computer, satellite, and information technologies in crop production, he has coordinated the InfoAg Conference series since 1994 and has developed other programs and exhibitions to demonstrate the use of precision technologies.

Dr. Reetz, right, receives his award from ASA President Dr. Ken Moore.

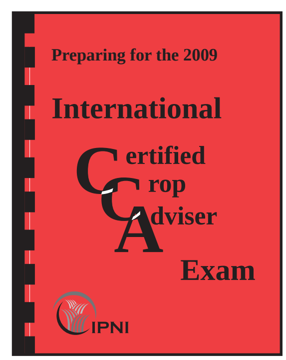
Dr. Bruulsema, right, receives the Fellow award from SSSA President Dr. Gary A. Peterson.

Dr. Tom W. Bruulsema, Northeast Regional Director, North America, was selected as Fellow of SSSA. Members of the Society nominate colleagues based on professional achievement and meritorious service, and only up to 0.3% of the Society's active and emeritus membership may be elected Fellow. Dr. Bruulsema holds B.Sc. and M.Sc. degrees in crop science from the University of Guelph and a Ph.D. in soil science from Cornell University. His research and education programs focus on responsible, science-based management of plant nutrition. Among recent publications he has edited are *Managing Crop Nitrogen for Weather* and *Quantifying and Understanding Plant Nitrogen Uptake for Systems Modeling* BC.

Preparing for the 2009 International Certified Crop Adviser Exam—Study Guide Available from IPNI

Individuals preparing for the 2009 International Certified Crop Adviser (ICCA) exam will be interested to know that an updated edition of the popular study guide offered by IPNI is now available. The 175-page training guide is organized and updated each year by Dr. John Gilmour, Professor Emeritus, University of Arkansas, and published by IPNI.

The ICCA exam is based on performance objectives considered as areas of expertise that a Certified Crop Adviser should possess. The performance objectives areas are: Nutrient Management, Soil and Water Management; Integrated Pest Management; and Crop Management. The study guide presents subject information for each performance objective, supplemented by sample questions. The study guide includes an answer key for the sample questions.



The 2009 edition of the ICCA exam study guide (Item #50-1000) is available for purchase directly from IPNI. The price of US$45.00 includes shipping and handling. 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.

The ICCA exam study guide may also be purchased on-line by visiting this URL: >www.ipni.net/ccamanual<. 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/bettercrops<**

Nitrogen Fertilization of Winter Wheat—Alternative Sources and Methods

By Ross H. McKenzie, Allan B. Middleton, Eric Bremer, and Tom Jensen

Research results evaluating N sources and placement methods at planting in the early fall for winter wheat production show that controlled release urea (CRU) can be either seed-row or side-band placed while regular urea performs better when side-banded. These N fertilizer methods are considered as feasible replacements to the previously recommended practice of applying the majority of N as ammonium nitrate (AN) in early spring.

A formerly recommended N fertilization practice for winter wheat production was to apply no N or a low rate of N fertilizer at planting, then broadcast the remainder of N required as AN in early spring (Fowler, 2002). Due to the recent removal of AN as a generally available commercial product in the Northern Great Plains Region, alternative strategies are required for N fertilization of winter wheat.

One strategy is to replace AN with urea as the N source and apply it in the early spring, but this can sometimes result in unwanted losses due to ammonia volatilization when urea is hydrolyzed on the surface from the action of urease enzyme present in soil and crop residues. Another method is to apply the N at the time of planting in the early fall. It can be placed in the seed-row, but this can result in excessive ammonia toxicity damage to germinating seed when normally required N rates are used. An alternative way to allow use of urea at planting is to side-band the N away from the seed-row. Yet another way is to replace regular urea with CRU in the seed-row at planting. The objective of this study was to evaluate the effectiveness of seed-row and side-banded urea and CRU at the time of winter wheat planting.

Field experiments were conducted at three locations in 2002-03, 2003-04, and 2004-05 (**Table 1**). In the Canadian and U.S. taxonomic systems, soils at the Bow Island site were Brown Chernozemic and Aridic Borolls. At the Lethbridge, Magrath, and Spring Coulee sites, they were Dark Brown Chernozemic and Typic Borolls. Locations had been no-till seeded for a period of at least 3 years prior to study initiation. The Bow Island location was in a fallow-spring wheat rotation, while other locations were continuously cropped. The experiment evaluated different options of applying N fertilizer at seeding in mid-September. The experiment consisted of three treatment factors: 1) N placement—seed-placed vs. side-banded, 2) fertilizer type—20-day CRU (ESN), 40-day CRU, and conventional urea, and 3) N rate—0, 27, 54, 80, and 107 lb N/A. The CRU products had polymer coatings that provide a gradual release of all urea within 20 days or 40 days when immersed in water at 73 °F (Agrium Inc., Calgary, Alberta). Plots were arranged in a split-plot design with three blocks, with N placement as main plot treatment and fertilizer type and N rate as sub-plot treatments.

Controlled release urea (20-day).

Table 1. Site characteristics.

Year	Site	Location	Soil Series	Texture[1]	Previous crop	Soil NO_3-N lb N/A	Soil pH
2002-03	BI03	Bow Island	Chin	SiL	Fallow	40	6.1
	LB03	Lethbridge	Lethbridge	CL	Wheat	13	7.3
	MG03	Magrath	Cradduck	CL	Wheat	6	7.5
2003-04	BI04	Bow Island	Chin	SiL	Fallow	36	6.6
	LB04	Lethbridge	Lethbridge	CL	Wheat	39	7.4
	SC04	Spring Coulee	Cradduck	CL	Wheat	18	7.2
2004-05	BI05	Bow Island	Chin	SiL	Fallow	25	6.2
	LB05	Lethbridge	Lethbridge	CL	Wheat	16	7.7
	SC05	Spring Coulee	Cradduck	CL	Wheat	25	5.9

[1]SiL = Silt loam; CL = Clay loam.

Soil samples were obtained just before seeding. Five soil cores (2 in. diameter per site) were combined for sample depths of 0 to 6 in., 6 to 12 in., 12 to 24 in., and 24 to 36 in. Samples were air-dried and ground to pass a 0.08 in. sieve. All samples were analyzed for extractable NO_3-N, P, K, and SO_4-S. Soil pH and electrical conductivity were determined in 2:1 water extracts.

Winter wheat cultivar AC Bellatrix was no-till planted with a small-plot seeder equipped with Stealth openers (Flexi-Coil, Saskatoon, Saskatchewan). Seedbed utilization was approximately 10%. Plots were seeded at a target plant density of 23 plants/ft^2, based on germination counts (approximately 95%) and an assumed seedling mortality of 15%. Each plot contained eight rows of winter wheat at a row spacing of 7 in. The outer rows of each plot were separated by a distance of 21 in. All plots received 19 lb P_2O_5/A as triple superphosphate applied with the seed. Weed control was achieved with recommended herbicides.

Plant density was determined in the last week of October and at the 2- to 3-leaf stage in the spring. Plant counts were determined in an area of 3.9 ft^2 in each plot.

Plots were trimmed to a length of 23 ft. prior to harvest and whole plots (107 ft^2) were harvested with a small-plot grain combine. Grain protein concentration was determined using near infrared spectroscopy. Grain N yield was estimated assuming a protein to N ratio of 5.7. All yields and concentrations are reported on a 14% moisture basis.

When N fertilizer was side-banded, plant densities were unaffected by fertilizer type or rate of N application. When N fertilizer was seed-placed, plant densities were reduced

Abbreviations and notes for this article: N = nitrogen; NO_3^- = nitrate; P = phosphorus; K = potassium; S = sulfur; SO_4 = sulfate.

Controlled release urea (20-day).

by urea at most sites when application rates exceeded 27 or 54 lb N/A, but were unaffected by application of the two CRU types (**Figure 1**). Use of CRU was highly effective for reducing seedling damage to winter wheat caused by seed-row application of urea. Current recommendations for maximum safe rates of seed-placed urea for cereals range from 0 to 36 lb N/A, depending on soil texture, row spacing, seedbed utilization, and moisture conditions (Karamanos et al., 2004). The recommended maximum safe rate of urea for our equipment and soil types is approximately 27 lb N/A under good moisture conditions, with a substantial reduction recommended under dry soil conditions. These recommendations were valid for most locations in our study. Stand density declined significantly at most locations when the rate of seed-placed urea was increased from 27 to 54 lb N/A (**Figure 1**). In contrast, application of CRU did not reduce stand density at application rates up to 107 lb N/A, even when applied under dry conditions (**Figure 1**).

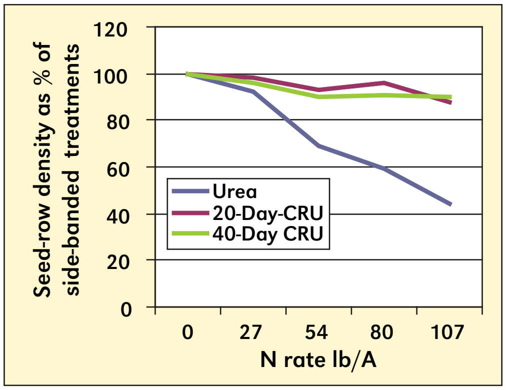


Figure 1. Effect of seed-placed fertilizer type and application rate on stand density of winter wheat at the 2- to 3-leaf stage in the spring. Nine-site average is expressed relative to the average stand density of side-banded treatments, which were unaffected by fertilizer type or application rate (standard deviation = 9).

At almost all sites, N fertilizer provided a highly significant increase in grain yield, protein concentration, and N uptake (**Table 2**). The average increase was 21% for grain yield, 13% for grain protein concentration, and 36% for grain N uptake.

Table 2. Average N response due to N fertilizer application (excluding seed-placed urea treatment).

	Grain yield, bu/A		Grain protein conc., %		Grain N yield, lb N/A	
Site	No N	N response	No N	N response	No N	N response
BI03	74	17*	7.3	1.6*	57	29*
LB03	79	13*	9.9	1.0*	82	23*
MG03	47	33*	7.1	1.0*	34	34*
BI04	79	6*	9.3	1.2*	77	15*
LB04	111	13*	7.5	1.3*	86	28*
SC04	76	15*	10.8	1.1*	85	27*
BI05	69	15*	7.8	1.7*	56	28*
LB05	91	20*	9.8	0.2 NS	93	22*
SC05	80	19*	8.4	0.8*	71	25*
All	78	17*	8.7	1.1*	71	26*

Average gain due to N fertilizer application; asterisk indicates statistical significance (*p = 0.05; NS = non significant).

Application of CRU significantly increased grain yield compared to seed-placed urea, but did not significantly increase grain yield compared to side-banded urea in our study at rates N rates greater than 54 lb N/A (**Figure 2**). Earlier studies often found that CRU products reduced grain yields because N release was incomplete or too slow to meet crop growth demands (Mahli and Nyborg, 1992, Delgado and Mosier, 1996). A study with a similar product (40-day release CRU) at eleven locations in Alberta and Saskatchewan found that CRU did not increase grain yield of spring wheat compared to side-banded urea, but increased grain protein concentrations at two of eleven locations and increased N fertilizer use efficiency by an average of 4% (Haderlein et al., 2001). Increased N availability during later growth is an effective means to improve grain protein concentration of cereals (Wuest and Cassman, 1992), but the release of N from the CRU used in our study was rapid enough to increase crop yield but may be too rapid to ensure increased grain protein concentration for winter wheat.

Fall application of CRU, either seed-placed or side-banded, and urea side-banded were effective means of supplying N for winter wheat in southern Alberta. Seed-placed regular urea reduced plant stand density and yields at N rates greater than 54 lb N/A. Application of CRU did not reduce stand density when seed-placed at rates as high as 107 lb N/A, although further study is required to confirm the safety of these rates under conditions less favorable for plant survival. Grain yield, protein concentration, and N uptake were similar for seed-row, and side-banded CRU and side-banded urea. BC

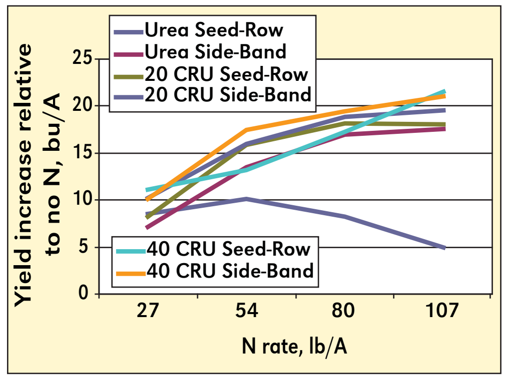


Figure 2. Effect of fertilizer placement, type, and application rate on the increase in grain yield relative to unfertilized check (all sites average, standard deviation 8 bu/A).

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Site-Specific Nutrient Management Performance in a Rice-Wheat Cropping System

By H.S. Khurana, Bijay-Singh, A. Dobermann, S.B. Phillips, A.S. Sidhu, and Yadvinder-Singh

A site-specific approach to nutrient management was evaluated in 56 on-farm experiments with irrigated wheat and transplanted rice crops in Northwest India. The agronomic and economic performance of this approach was compared with current farmer fertilizer practices for 2 years.

Recent research conducted in many Asian countries, including Northwest India (Ladha et al., 2003; Pathak et al., 2003), has demonstrated limitations of the current approach of fixed-rate, fixed-time (blanket) fertilizer recommendations being made for large areas. This is mainly because the approach does not take into account the existence of large variability in soil nutrient supply and site-specific crop response to nutrients among farms (Timsina and Connor, 2001). This helps to explain why fertilizer N use efficiency is usually poor, the use of P and K fertilizers is often not balanced with crop requirements and other nutrients and, as a result, profitability is not optimized (Dobermann et al., 1998; Olk et al., 1999).

Based on these conclusions, the original concept of site-specific nutrient management (SSNM) to manage among-farm nutrient variability was developed in Asia for rice (Dobermann and White, 1999). We conducted a series of on-farm experiments with rice and wheat crops at 56 farmer fields in Northwest India to test the hypothesis that rice and wheat yields, profit, plant nutrient uptake, and fertilizer efficiencies can be increased significantly through field-specific nutrient management. In this article, we evaluate the performance of SSNM compared to prevailing farmer practices.

Rice-wheat is the dominant cropping system of Punjab Province in Northwest India, where rice is grown in the summer months (mid-June to October), followed by wheat in the winter months (November to mid-April) and a small fallow period from mid-April to mid-June. We conducted on-farm experiments from 2002-03 to 2004-05 with irrigated wheat and transplanted rice at 56 sites in six rice-wheat production regions across the three major agro-climatic zones of Punjab. The regions in which on-farm experiments were conducted were Gurdaspur, Hoshiarpur, Ludhiana, Patiala, Faridkot, and Firozpur. The experimental set-up followed a standard protocol at all sites and included nutrient omission plots (0-N, 0-P, 0-K) to estimate indigenous nutrient supplies, a SSNM treatment plot, and farmer fertilizer practice (FFP) plot in each farmer field. Researchers did not intervene in the FFP plots, but managed fertilizer application in the SSNM and nutrient omission plots. Farmers were responsible for all other aspects of general crop and pest management and the choice of variety. Treatments (SSNM and FFP) were compared on 56 farms over a period of 2 cropping years (2003-04 and 2004-05).

An estimate of soil indigenous N, P, and K supply was obtained from omission plots situated in each farmer field. The results from these plots were used as inputs in a model designed to estimate field-specific fertilizer requirements for the rice and wheat crops in the SSNM plots (Khurana et al., 2007; Khurana et al., 2008).

Soil nutrient supplies varied widely, and two- to four-fold ranges were found for each nutrient and site (**Tables 1 and 2**). Average rice grain yields in nutrient omission plots increased in the order 0-N (3.82) <0-K (5.41) ≤0-P (5.45 t/ha), while the corresponding values for wheat were 0-N (3.08) <0-K (4.35) ≤0-P (4.55 t/ha). These data confirm that N deficiency is a general feature of irrigated rice-wheat systems in Punjab, whereas P and K supply are equally limiting factors, especially when considering the average rice and wheat yield goals of 7.9 t/ha (Khurana et al., 2007) and 5.8 t/ha (Khurana et al. 2008), respectively, for Punjab.

Performance indicators used for the agronomic and economic evaluation of SSNM and FFP were:

- Recovery efficiency of fertilizer N (REN) is the increase in plant N uptake per unit fertilizer N applied (kg plant N/kg fertilizer N).
- Physiological N efficiency (PEN) is the increase in grain per unit increase in plant N uptake from fertilizer (kg grain/kg plant N).
- Agronomic N use efficiency (AEN) is the product of REN and PEN, expressed as the yield increase per unit fertilizer N applied (kg grain yield/kg fertilizer N).
- Gross return over fertilizer costs (US$/ha/crop) is calculated as revenue (grain yield x farm gate paddy and

Table 1. Variability of grain yield and plant nutrient accumulation in nutrient omission plots across 56 irrigated, transplanted rice farms in Punjab, India. Descriptive statistics are based on three rice crops sampled at each farm from 2002 to 2004.

Measurement†	Mean	SD	Min.	Max.	CV among sites in each region‡, %
Grain yield in 0-N plot, t/ha	3.82	0.99	1.8	5.6	16 (12-25)
Grain yield in 0-P plot, t/ha	5.45	1.24	2.7	7.6	10 (6-16)
Grain yield in 0-K plot, t/ha	5.41	1.01	3.1	7.7	10 (7-13)
Plant N in 0-N plot, kg/ha	51.1	15.3	19.8	86.6	18 (12-27)
Plant P in 0-P plot, kg/ha	15.7	4.18	7.8	25.1	18 (13-28)
Plant K in 0-K plot, kg/ha	83.6	21.4	48.4	124	12 (9-14)

† 0-N: N omission plot; 0-P: P omission plot; 0-K: K omission plot.

‡ Coefficient of variation computed from site-specific average values for three wheat crops each sampled in 2003, 2004, and 2005 at each site. Values shown are the mean CV within a region and its range at the six regions (in parenthesis). For each crop, measurements of two replications at each site were combined into a site average. Site averages were then used to compute within-region CV for each crop at each site. These CV values were then used to calculate the average CV for each region across all crops sampled.

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

wheat prices) minus fertilizer cost.

Compared with FFP, SSNM significantly increased grain yield in all regions in the two wheat and rice crops (**Figure 1**). But there was no significant difference between the 2 years of experimentation, which helped us pool the year-wise data for grain yield for each region. On average, SSNM generated a yield gain of at least 0.9 (17%) and 0.5 t/ha (12%) in rice and wheat crops, respectively, compared with FFP in approximately 48% of the sites studied. At 21 of the total 56 farms studied, rice grain yield increases were ≥1 t/ha with SSNM compared with FFP, while at 24 of the total 56 farms studied, wheat grain yield increases were ≥0.8 t/ha, showing the potential of the SSNM approach used. Another interesting observation was that the maximum increases in rice and wheat grain yields were obtained at sites with low fertility soils, while the regions with high fertility soils had minimum, but significant, increases in grain yields of rice and wheat crops. This corroborates our hypothesis that blanket fertilizer recommendations, as is the current norm in Punjab, are of limited use in tackling site-specific soil fertility problems and that the adoption of site-specific strategies can give some impetus to the productivity growth of rice and wheat crops.

Table 2. Variability of grain yield and plant nutrient accumulation in nutrient omission plots across 56 irrigated wheat farms in Punjab, India. Descriptive statistics are based on three wheat crops sampled at each farm from 2003 to 2005.

Measurement†	Mean	SD	Min.	Max.	CV among sites in each region‡, %
Grain yield in 0-N plot, t/ha	3.08	0.85	1.1	4.4	21 (13-35)
Grain yield in 0-P plot, t/ha	4.55	1.02	2.1	6.1	12 (7-19)
Grain yield in 0-K plot, t/ha	4.35	0.81	2.3	6.0	12 (8-19)
Plant N in 0-N plot, kg/ha	66.3	15.7	26.1	94.8	15 (11-23)
Plant P in 0-P plot, kg/ha	15.5	4.09	7.5	23.8	19 (13-26)
Plant K in 0-K plot, kg/ha	79.1	18.8	35.9	115	13 (10-17)

† 0-N: N omission plot; 0-P: P omission plot; 0-K: K omission plot.

‡ Coefficient of variation computed from site-specific average values for three wheat crops each sampled in 2003, 2004, and 2005 at each site. Values shown are the mean CV within a region and its range at the six regions (in parenthesis). For each crop, measurements of two replications at each site were combined into a site average. Site averages were then used to compute within-region CV for each crop at each site. These CV values were then used to calculate the average CV for each region across all crops sampled.

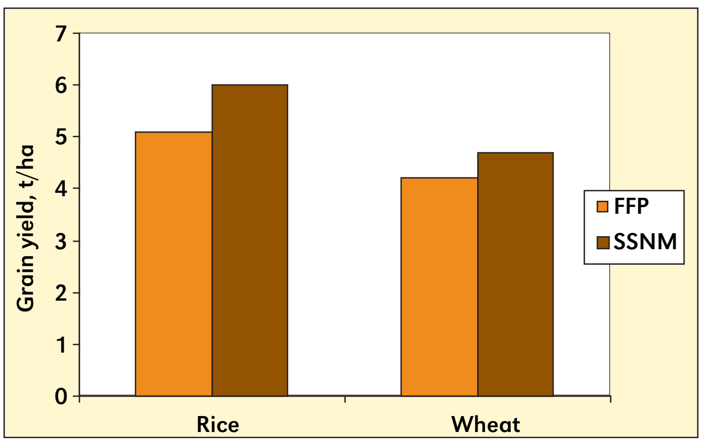

Figure 1. Grain yield of rice and wheat crops in FFP and SSNM averaged for 2 years.

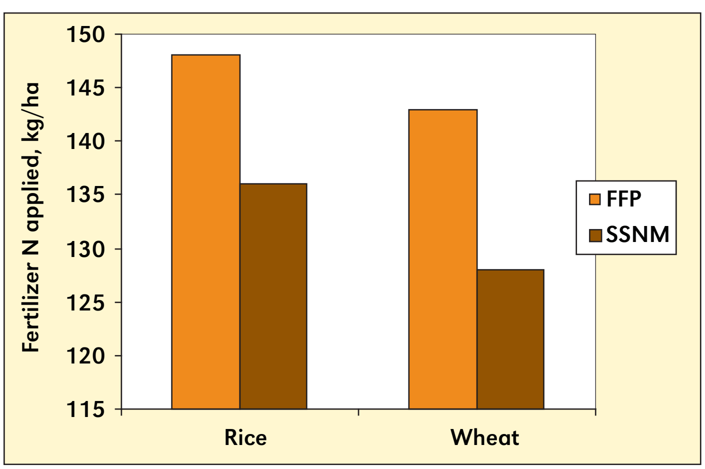

Figure 2. Fertilizer N applied to rice and wheat crops in FFP and SSNM averaged for 2 years.

Average fertilizer N applied to the rice and wheat crops in FFP at all sites in Punjab (148 and 143 kg N/ha, respectively) was relatively higher than the fertilizer N applied in other parts of India (Dobermann et al., 2002; Pathak et al., 2003). However, most farmers had no means of adjusting their fertilizer rates according to the actual soil fertility status. Correlation between N rate and indigenous N supply (INS) in wheat was -0.16, clearly outlining why…despite higher N use under FFP (**Figure 1**)…grain yield and N accumulation were low as compared with that under SSNM. Like N, P rates were also not significantly correlated with indigenous P supply (IPS) (r = -0.05 and = 0.01 for wheat and rice, respectively). On the other hand, fertilizer K application in FFP was not much in Punjab probably because of substantial contribution of K (6 to 51 kg K/ha with an average of 29 kg K/ha) from irrigation water.

On average, SSNM saved a significant amount (8 and 10% for rice and wheat, respectively) of fertilizer N compared with FFP (**Figure 2**), clearly bringing out the positive effect of SSNM for N. In contrast, average fertilizer P application significantly increased in rice and remained the same in wheat in both SSNM and FFP treatments, while fertilizer K application was significantly increased with SSNM compared with FFP for both rice and wheat crops. This might be because 10 and 30 kg/ha P and K, respectively, were set as the minimum amounts to be applied to replenish net removal of these nutrients from a site and minimize risk of any macronutrient deficiency.

Significant increases in N use efficiency were achieved in rice and wheat through the field-specific N management practiced in the SSNM treatment (**Figure 3**). In general, compared with the FFP, less fertilizer N was applied (**Figure 2**), and AEN, REN, and PEN were significantly increased with SSNM. On average, AEN was increased by 7.3 kg/kg (83%) and 5.3 kg/kg (63%), REN by 0.10 kg/kg (50%) and 0.10 kg/kg (59%), and PEN by 9.5 kg/kg (27%) and 7.7 kg/kg (26%) in rice and wheat crops, respectively. This increase was attributed to more uniform N applications among sites under SSNM as compared to under FFP. Also, the N applications were spread more evenly through the growing season and avoided heavy

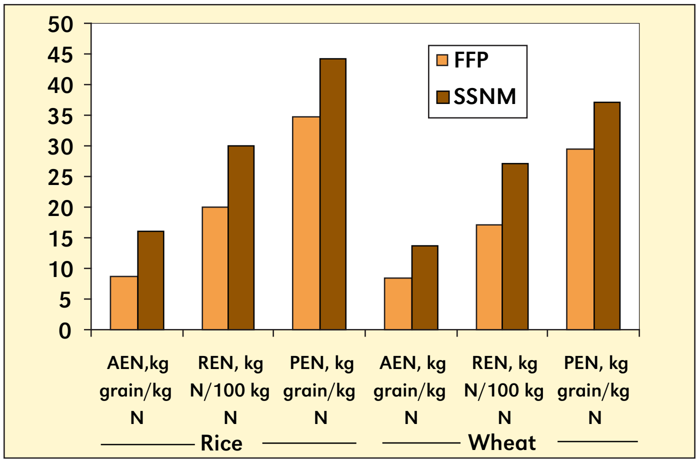

Figure 3. Fertilizer N use efficiencies in rice and wheat crops in FFP and SSNM averaged for 2 years.

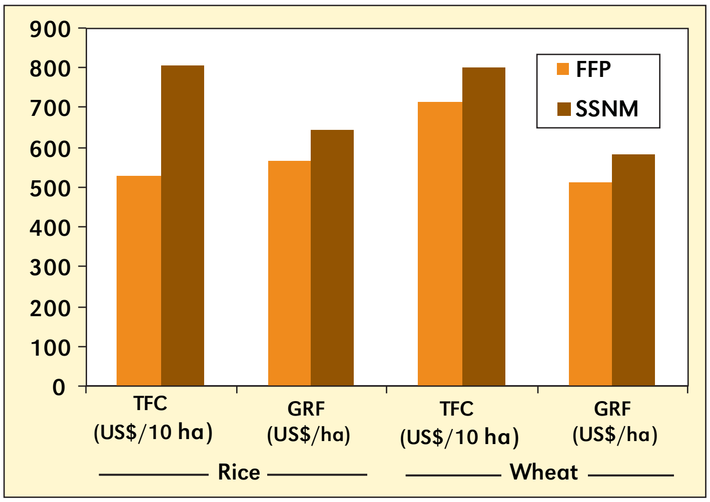

Figure 4. Total fertilizer cost (TFC) and gross returns above fertilizer cost (GRF, profitability) in rice and wheat crops in FFP and SSNM averaged for 2 years. (Prices used were: N fertilizer US $0.32 per kg N; P fertilizer US $1.81 per kg P; K fertilizer US $0.50 per kg K; price of wheat grain US $0.14 per kg; and price of paddy US $0.12 per kg. Numbers are based on 2005 values, when the study was conducted. Conversion rate: US$1.00 = Rs.46.2).

single applications at early growth stages of rice-wheat crops when compared with FFP.

Site-specific nutrient management led to an increase in the average fertilizer cost (US$8.60/ha/crop [12%] in wheat and US$27.30/ha/crop [52%] in rice), but comparatively a larger increase in gross returns over fertilizer (GRF) (US$67.70/ha/crop [13%] in wheat and US$79.30/ha/crop [14%] in rice) compared with FFP (**Figure 4**). Increase in the average fertilizer cost under SSNM was mainly attributed to an increase in K fertilizer use – an important input from the balanced crop nutrition point of view, but one that is generally skipped by farmers in Punjab.

Conclusions

Field-specific management of macronutrients increased yields of rice and wheat crops by 12 and 17% and profitability by 14 and 13%, respectively, in Northwest India. Results suggest that further increases in yield can only be expected when farmers exploit the synergy that occurs when all aspects of crop, nutrient, and pest management are improved simultaneously. Increased nutrient uptake and N use efficiency across a wide range of rice-growing environments with diverse climatic conditions were related to the effects of improved N management and balanced nutrition. A major challenge is to simplify the approach for wider scale dissemination without sacrificing components that are crucial to its success. The underlying principles of SSNM need to be carefully identified and evaluated for each macronutrient. Approaches to further dissemination must be related to prevailing site-specific conditions. BC

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Optimizing Yield and Benefit in Doublecropped Wheat-Maize Rotations

By Ping He, Shutian Li, and Ji-yun Jin

Balanced fertilization based on soil testing generated high crop yields, while mean net returns over common farm practice were significant regardless of the chosen price scenario for grain and fertilizer.

The single year winter wheat-summer maize rotation is the most important agricultural production system in the North Central China Plain. High cropping intensity can commonly expose this doublecrop system to risks associated with unbalanced and excess use of N fertilizer (Zhao, 2006). Continuous winter wheat and summer maize cropping without balanced and efficient use of fertilizers has not only contributed to losses in yield and profit, but also to environmental problems such as groundwater NO_3-N contamination and eutrophication of rivers.

Rational nutrient management on these farmlands is needed for sustainable crop production and environmental protection. This study conducted field experiments within the North Central China Plain to explore the potential benefits associated with soil test-based balanced fertilizer application within an improved nutrient management system. Given the recent increases in both grain prices and fertilizer cost, an opportunity also arose to compare a series of price/cost scenarios within a simple 'what-if' analysis.

The field research included four winter wheat and four summer maize experiments placed within farmer fields in Hebei, Henan, Shandong, and Shanxi Provinces from 2006 to 2007 (**Table 1**). Prior to each sowing, soil samples (0 to 20 cm) were collected and analyzed for nutrient status. Soil nutrients were determined with procedures applied by the National Laboratory of Soil Testing and Fertilizer Recommendation as the method described by Porch and Hunter (2002). According to a typical winter wheat/summer maize rotation system, wheat was sown at the beginning of October and harvested at mid June of the next year (**Table 2**). Maize was sown immediately after the wheat harvest, without tillage, and was harvested at the end of September.

Each experiment was designed in a randomized complete block with six treatments and three replicates. Treatments included a check without fertilizer (CK), a soil test-based balanced "optimum" nutrient application (OPT), and a series of nutrient omission treatments including OPT-N, OPT-P, OPT-K, and farmer practice (FP) (**Table 3**). Urea, single superphosphate, potassium chloride, and zinc sulfate were selected as fertilizer sources. All other limiting nutrients in addition to N, P, and K were applied to all treatments prior to sowing.

The timing of fertilizer application differed between sites, but with the exception of the Henan site, followed traditional farm practice. In Shanxi, all N, P, and K fertilizers were applied basally before sowing for winter wheat and summer maize. For wheat in Shandong, 60% of the N and all of the P and K were applied basally and the remaining N was top dressed in early spring before tillering. In maize, half of the N and all of the P and K were applied basally, and the remaining N was top dressed during stalk elongation. In Hebei, wheat and maize both received one third of the N and all of the P and K basally, and the remaining N was top dressed. In Henan, both wheat and maize received half of the N, all of the P, and half of the K basally and the remaining nutrients were topdressed. This differed from the FP treatment which received all of the K at planting time. Irrigation, insect-control, inter-row tillage and other management activities were conducted according to farmers' practice.

Harvested seed and straw samples were randomly collected and oven-dried at 60°C for determination of dry matter weight, and analyzed for total N, P, and K. Plant samples were

Table 1. Physical and chemical properties of tested soils.

Location	Year	Soil type	pH	OM	K	NH_4-N	P	Zn
				%	--------	mg/L	--------	
Shanxi	2006/07	Calcic cinnamon	8.1	0.35	72.2	3.1	21	1.1
Shanxi	2007	Calcic cinnamon	8.4	0.55	126.9	2.7	25	1.8
Hebei	2006/07	Fluvo-aquic	8.4	0.70	78.4	4.9	22	1.1
Hebei	2007	Fluvo-aquic	8.3	0.78	71.1	5.8	45	1.1
Shandong	2006/07	Brown	4.4	1.20	45.2	8.9	59	2.1
Shandong	2007	Brown	4.7	1.00	57.2	21.6	94	1.7
Henan	2006/07	Brown	7.7	1.16	98.9	25.1	21	2.0
Henan	2007	Brown soils	7.9	0.86	77.2	29.6	20	1.0

Table 2. Schedule of crop planting and harvests.

Province	Year	Crop/Variety	Seeding rate	Seeding date	Harvest date	Plot size, m^2
Shanxi	2006/07	Wheat/Jinmai 81	225 kg/ha	Oct. 8, 2006	June 12, 2007	26
Shanxi	2007	Maize/Jindan 958	57,600 plants/ha	June 12, 2006	Oct. 16, 2007	25
Hebei	2006/07	Wheat/Shimai 17	225 kg/ha	Oct. 12, 2006	June 10, 2007	45
Hebei	2007	Maize/Zhengdan 958	63,000 plants/ha	June 17, 2007	Oct. 9, 2007	40
Shandong	2006/07	Wheat/Jinan 17	225 kg/ha	Oct. 12, 2006	June 19, 2007	20
Shandong	2007	Maize/Zhengdan 958	60,000 plants/ha	June 23, 2007	Oct. 10, 2007	32
Henan	2006/07	Wheat/ZM98165	150 kg/ha	Oct. 14, 2006	June 5, 2007	32
Henan	2007	Maize/Zhengdan 958	75,000 plants/ha	June 12, 2007	Oct. 3, 2007	32

Abbreviations and notes for this article: N = nitrogen; P = phosphorus. K = potassium; NO_3^- = nitrate; NH_4^+ = ammonia.

Table 3. Fertilizer treatment design for wheat and maize in 2006-2007.

		Wheat			Maize		
		Nutrient application, kg/ha					
Province	Treatments	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Shanxi	OPT	195	90	150	225	90	120
	OPT-N	0	90	150	0	90	120
	OPT-P	195	0	150	225	0	120
	OPT-K	195	90	0	225	90	0
	FP	173	144	0	345	0	0
	CK	0	0	0	0	0	0
Hebei	OPT	180	100	75	270	45	120
	OPT-N	0	100	75	0	45	120
	OPT-P	180	0	75	270	0	120
	OPT-K	180	100	0	270	45	0
	FP	300	150	0	160	48	72
	CK	0	0	0	0	0	0
Shandong	OPT	240	30	120	150	0	120
	OPT-N	0	30	120	0	0	120
	OPT-P	240	0	120	150	60[1]	120
	OPT-K	240	30	0	150	0	0
	FP	113	113	113	75	75	75
	CK	0	0	0	0	0	0
Henan	OPT	210	90	60	240	90	120
	OPT-N	0	90	60	0	90	120
	OPT-P	210	0	60	240	0	120
	OPT-K	210	90	0	240	90	0
	FP	360	210	135	450	225	225
	CK	0	0	0	0	0	0

[1]60 kg/ha P_2O_5 was applied for the OPT-P treatment to verify the accuracy of the zero P level in the OPT treatment predicted by soil test results.

Table 4. Grain yields of wheat and maize in 2006-2007.

	Shanxi				Hebei			
	Wheat		Maize		Wheat		Maize	
Treatments	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%
OPT	6,652 a	100	8,298 a	100	6,317 a	100	8,811 a	100
OPT-N	5,848 b	88	6,286 c	76	4,767 bc	75	7,735 b	88
OPT-P	6,218 ab	94	7,921 ab	96	5,750 ab	91	7,984 ab	91
OPT-K	6,164 ab	93	8,224 a	99	6,167 a	98	7,922 ab	90
FP	6,196 ab	93	7,408 b	89	5,625 ab	89	7,568 b	86
CK	5,712 b	86	5,627 d	68	3,883 c	61	7,489 b	85
	Shandong				Henan			
	Wheat		Maize		Wheat		Maize	
Treatments	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%
OPT	6,199 a	100	5,032 a	100	8,760 a	100	12,051 a	100
OPT-N	4,291 cd	69	3,750 b	75	7,987 c	91	11,156 b	93
OPT-P	3,855 d	62	4,393 ab	87	8,277 ab	94	11,583 ab	96
OPT-K	4,978 bc	80	4,650 ab	92	8,212 ab	94	11,239 b	93
FP	5,881 ab	95	4,756 ab	95	8,688 ab	99	11,754 ab	98
CK	3,855 d	62	4,493 ab	89	7,887 c	90	10,400 c	86

The same letter in the same column indicated no significant at P=0.05

digested using wet oxidation, total N was determined using the Kjeldahl method, P was determined by vanadomolybdate yellow color development, and K was analyzed by flame spectrophotometers (Analysis Approach of Soil Agro-chemical Analysis, 2000).

Yields of Wheat and Maize

Crop yield comparisons across sites indicate that yields in Shanxi and Hebei were higher than those in Shandong where yields were severely limited under nutrient omission (**Table 4**). Yields of both wheat and maize in Henan were highest among provinces as this site benefits from being situated within a highly productive zone having continuous and high input of fertilizers and therefore higher residual soil fertility. High yields within the unfertilized check treatments, and a relatively small response to applied N in wheat (773 kg/ha) and maize (895 kg/ha), further supports the high yield potential ranking for the Henan site. Nitrogen was generally the most limiting factor for the wheat/maize system in all provinces, followed by P and K. The OPT treatments significantly increased maize yields over FP by 12% and 16% in Shanxi and Hebei, respectively. However, maize yields under the OPT treatments in Shandong and Henan were not statistically better than FP, and the set of OPT treatments were unable to significantly increase winter wheat beyond those obtained under FP at any of the sites.

Nutrient uptake followed trends similar to those observed for yields. The OPT treatments achieved the highest values in each crop followed by FP (data not shown). Nutrient use efficiency can be expressed as partial factor productivity (PFP), agronomic efficiency (AE), and crop recovery efficiency (RE) (Fixen, 2007). Here we use AE and RE to evaluate balanced fertilization, 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 applied. Measurements of AE for applied N, P, and K resulted in large crop-to-crop and location-to-location variability. Mean AE values were 6.1 kg/kg N, 23.5 kg/kg P_2O_5, and 6.1 kg/kg K_2O for wheat, and 6.3 kg/kg N, 9.6 kg/kg P_2O_5, and 4.5 kg/kg K_2O for maize (**Table 5**). The high AE value of 78.1 kg/kg P_2O_5 resulted from the low P_2O_5 application rate (30 kg P_2O_5/ha) on winter wheat in Shandong. Under the OPT treatment, each 100 kg seed required 2.95 kg N, 0.87 kg P_2O_5 and 2.42 kg/kg K_2O for wheat, and 2.29 kg N, 0.67 kg P_2O_5 and 2.31 kg/kg K_2O for maize. Nutrients taken up by plants are not only derived from fertilizer applied, but also from the indigenous supplies from soil, atmosphere, irrigation water, etc. The mean RE values of N, P_2O_5, and K_2O for the first season were 27%, 23%, and 26% for wheat, and 24%, 12%, and 33% for maize, respectively.

The economic benefit from fertilizer application was calculated under three scenarios: (a) using actual crop product values and fertilizer prices at the time

Table 5. Nutrient use efficiency[1] of N, P_2O_5, and K_2O.

		Shanxi		Hebei		Shandong		Henan		Mean	
	Nutrient	Wheat	Maize	Wheat	Maize	Wheat	Maize	Wheat	Maize	Wheat	Maize
Agronomic efficiency, kg/kg	N	4.1	8.9	8.6	4.0	7.9	8.5	3.7	3.7	6.1	6.3
	P_2O_5	4.8	4.2	5.7	18.4	78.1	10.6	5.4	5.2	23.5	9.6
	K_2O	3.2	0.6	2.0	7.4	10.2	3.2	9.1	6.8	6.1	4.5
Nutrient uptake, kg/100 kg seed	N	3.17	2.31	2.63	2.15	2.39	2.77	3.62	1.92	2.95	2.29
	P_2O_5	0.79	0.76	0.94	0.58	0.50	0.61	1.25	0.74	0.87	0.67
	K_2O	2.05	2.11	1.98	1.79	2.21	3.09	3.44	2.26	2.42	2.31
Recovery efficiency, %	N	36.8	33.8	29.0	13.5	19.6	24.2	24.2	22.9	27.4	23.6
	P_2O_5	9.9	15.0	6.6	14.7	48.9	ND[2]	25.7	13.4	22.8	12.2
	K_2O	25.3	17.6	10.0	18.9	25.0	51.8	43.7	41.9	26.0	32.6

[1]Nutrient use efficiency was calculated with nutrient uptake by OPT treatment. [2]ND = no data.

of the experiment – which preceded the current period of escalating values for both; (b) using current domestic prices which include some government subsidies; and (c) using current international market prices for crops and fertilizers. Crop profitability mirrored the yield responses and despite some marginal differences in yield the OPT treatment was more profitable than FP in each crop/rotation and each location. Comparing the OPT over FP, the mean added net return from the entire rotation under scenarios a, b, and c was US$331/ha, US$307/ha, and US$568/ha, respectively. From these results it is apparent that the Chinese Government subsidies in place failed to fully compensate for the higher cost structure faced by farmers. It is also apparent that profits based on the international market would be significantly higher.

With rising fertilizer prices in international markets, the average value-to-cost ratio (VCR) for the OPT and FP treatments decreased between pricing scenarios from 7.1 and 5.8 to 4.1 and 3.1 for wheat, and 8.7 and 8.4 to 5.5 and 5.1 for maize (**Table 6**). These VCR values also suggested that more return could be obtained from maize than from wheat, and provide another indicator of the advantage of adopting the OPT over FP. It is worth noting that although higher yields could be obtained with high inputs at the high-yielding site in Henan, the VCR was lowest for both wheat and maize under FP and provides a good example of the opportunity cost of excess and imbalanced fertilizer input. As a comparison, the balanced OPT treatments at Henan did produce the highest VCRs for both crops under all three of the price/cost scenarios.

Table 6. Value-to-cost ratio in wheat-maize rotation system.

		VCR[a]		VCR[b]		VCR[c]	
Province	Crops	OPT	FP	OPT	FP	OPT	FP
Shanxi	Wheat	5.3	6.3	4.0	5.0	3.5	3.6
	Maize	6.8	8.3	4.7	6.3	4.7	5.7
Hebei	Wheat	6.6	4.8	4.6	3.4	3.8	2.5
	Maize	7.8	10.4	5.3	6.8	5.3	6.7
Shandong	Wheat	7.3	7.4	4.4	4.3	3.9	3.7
	Maize	9.9	10.1	4.9	4.9	5.5	4.8
Henan	Wheat	9.0	4.5	6.5	3.3	5.2	2.6
	Maize	10.2	4.8	6.7	3.2	6.6	3.1
Average	Wheat	7.1	5.8	4.9	4.0	4.1	3.1
	Maize	8.7	8.4	5.4	5.3	5.5	5.1

Value cost ratio (VCR) = crop value/fertilizer cost. Small letters a, b, and c denote scenarios using prices for crops and fertilizer at: (a) the time of the experiment (2006/07) = 3.4 to 3.9 RMB/kg N, 4.4 to 6.5 RMB/kg P_2O_5, 3.4 to 4.3 RMB/kg K_2O; wheat = 1.4 to 1.6 RMB/kg, maize = 1.5 to 1.8 RMB/kg); (b) current domestic prices for May 2008 = 4.7 RMB/kg N, 7.1 RMB/kg P_2O_5, and 6.0 RMB/kg K_2O, wheat = 1.474 RMB/kg, maize = 1.376 RMB/kg); and (c) current international market prices for May 2008 = 8.2 RMB/kg N, 13.8 RMB/kg P_2O_5, and 6.3 RMB/kg K_2O, wheat = 1.987 RMB/kg, maize = 2.162 RMB/kg); exchange rate: US$1 = 6.9 RMB.

Although balanced fertilization increased both yields and benefits, AE and RE were relatively lower since N responses were less than 2 t/ha, and even less than 1 t/ha in Henan. Therefore, further best management practices (BMPs) should be integrated into common practice to improve fertilizer (especially N) efficiency in this highly intensified cropping system. BC

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Managing Plant Nutrients for World Food Needs

Price increases in crop commodities have precipitated concern about world food supplies. The forces driving the price increases call for ecological intensification of cropping systems. A recent scientific conference – Plants & Soils: Montreal '08 – featured four leading minds who brought out important implications for managing plant nutrients.

1. Better crops demand better science. Professor Ken Cassman, University of Nebraska, pointed out that current rates of gain in crop yields are not adequate to meet the expected demand for food, feed, fiber, and fuel. Future yield increases need to be achieved in the context of declining supplies of water for irrigation, and a higher relative cost of N fertilizer. Expansion of crop area is limited by lack of good quality soils and by concerns about loss of wildlife habitat and biodiversity. Ecological intensification—accelerated yield gain while reducing agriculture's environmental footprint—is the path forward, but depends on getting scientific breakthroughs in basic plant physiology, ecophysiology, agroecology, and soil science.

2. Healthy ecosystems are crucial. Professor Cal DeWitt, University of Wisconsin, spoke on plant and soil management in the context of the biosphere – the layer of life in the soil, water, and air that surrounds the globe. Exploring the issue of climate change, he showed how healthy ecosystems are central to the aspirations of humankind, and that a combination of science, ethics, and praxis is needed to conserve the biosphere. Science explains how the world works, ethics describes what ought to be, and praxis defines what we must do. The triad of science, ethics, and praxis applies to the management of plant nutrition.

3. Biofuels link energy and climate change. Professor Don Smith, McGill University, noted that biofuels address two great challenges of the 21st century: energy and climate change. Climate change is an energy issue since it is largely driven by use of fossil fuels. Science and technology are striving to improve biofuel crops to produce more energy per unit of energy consumed in their production. The design of biofuel production systems requires rigorous life-cycle analysis.

4. Are we "starving Peter to drive Paul"? Professor Tom Powers, University of Delaware, discussed the ethical questions that biofuels provoke, including violation of distributive justice, political instability, and harm to the interests of future generations. Our inability to resolve these problems may waste the precious social and political momentum that is attempting to address the challenge of global climate change. Moving beyond a "zero-sum game" requires that crops be more productive.

So what are the implications for managing plant nutrients? The linkages among food, fuel, and climate change mean that a choice between producing food and fuel is not realistic. Ecological intensification of cropping systems will be the path forward, and plant nutrient management needs to support it. The key is to work with a nutrient management system that appropriately applies global scientific principles to local crop management; a system that seeks to apply the right nutrient source at the right rate, time, and place. Crop producers and their advisers need to be selecting practices, on a site-specific basis, for their ability to preserve natural ecosystems by growing more on less land, with less loss of nutrients, recognizing longer-term effects on the soil ecology, and supporting profitable production.

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