BETTER CROPS
WITH PLANT FOOD

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2012 Number 1

Nutrient Management for High Citrus Yields in Tropical Soils

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...and much more

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BETTER CROPS WITH PLANT FOOD

Vol. XCVI (96) 2012, No. 1

Our cover: Orange orchard at the Nossa Senhora Aparecida farm, located in Bebedouro, São Paulo, Brazil.
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2011 IPNI Science Award Goes to Dr. Michael McLaughlin of CSRIO

The International Plant Nutrition Institute (IPNI) has named Dr. Michael J. McLaughlin of The University of Adelaide and the Commonwealth Scientific and Industrial Research Organisation (CSIRO), as the winner of the 2011 IPNI Science Award. He receives a special plaque plus a monetary award of USD 5,000.00 (five thousand dollars).

"We are honored to announce Dr. McLaughlin as the recipient of the IPNI Science Award. It is evident from his accomplishments that Mike is highly suited to receive this award," said Dr. Terry L. Roberts, President of IPNI. "His internationally recognized contributions to improved nutrient management and production agriculture through advancements in fertilizer chemistry, crop nutrition, and environmental protection are truly excellent. His career marks numerous breakthroughs in improved environmental assessment and management, the development of new fertilizer delivery systems, and a greater understanding of the interactions of nutrients and the environment."

Dr. Roberts also acknowledged the other outstanding nominees for the award, and encouraged future nominations of qualified scientists. Private or public sector agronomists, soil scientists, and crop scientists from all countries are eligible for nomination. This is the fifth year the IPNI Science Award has been presented. The previous recipient in 2010 was Dr. Andrew Sharpley of the University of Arkansas.

Born in Ballymena, Northern Ireland, Dr. McLaughlin received his B.Sc. degree from the University of Ulster, UK in 1977. He went on to earn his M. Agr. Sc. degree from the University of Reading, UK in 1979. Dr. McLaughlin then received his Ph.D. from the University of Adelaide in 1986 on the subject of P cycling in soils and the relative importance of crop residues and fertilizer to the P nutrition of cereal crops.

Since 2007, Dr. McLaughlin has been Foundation Director, University of Adelaide Fertiliser Technology Research Centre supported by The Mosaic Company and the Australian Grain Research and Development Corporation. In 2005, Dr. McLaughlin became Professor in Soil Science at the University's School of Agriculture, Food and Wine and since 2000, he has been Chief Research Scientist, CSIRO Land and Water, Adelaide. From 1999 to 2003, Dr. McLaughlin was Senior Principal Research Scientist, CSIRO Land and Water, Adelaide. Dr. McLaughlin is a Fellow of the American Society of America (ASA) and Soil Science Society of America (SSSA), and is a Fellow of the Australian Academy of Technological Sciences and Engineering. Dr. McLaughlin is also CSIRO Science Fellow in the Environmental Biogeochemistry Program, CSIRO Land and Water, as well as the Science Fellow, CSIRO Agricultural Sustainability Flagship. His awards and honors include Australian Soil Science Society Prescott Medal in 2009, 2008 Fluid Fertilizer Foundation Researcher of the Year, 2008 Soil Science Society of America International Award, 2005 CSIRO Land and Water Partnership Excellence Award, and the 2002 CSIRO Land and Water Chief's Award for excellence in research.

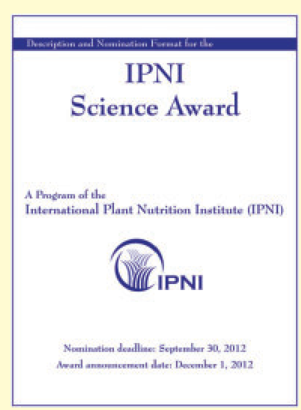
Dr. Michael J. McLaughlin

Dr. McLaughlin has published 28 book chapters, 184 journal papers, 52 refereed full conference papers, 262 conference abstracts, and over 120 other industry reports and publications. He holds 8 patents and since 1989 has won research grants valued at AUD 23.5 million. Dr. McLaughlin has supervised 20 Ph.D. Students and is actively involved with honors students in areas of biogeochemistry, fertilizer formulation, and environmental contamination. Dr. McLaughlin and his research group have been instrumental in developing and understanding of the mechanisms behind the effectiveness of fluid fertilizers in low rainfall cropping systems. As Foundation Director of the Fertilizer Technology Research Centre, Dr. McLaughlin is presently heading the development of leading edge fertilizer technologies to match nutrient supply to crop demand and identify new efficient fertilizer formulations, making extensive use of nanotechnology, and advanced tracing and imaging techniques to probe reactions of fertilizers with soils. Dr. McLaughlin has contributed greatly to the body of scientific work published on cadmium, heavy metal contamination in soils, and has directly influenced national and international public policy on developing science-based strategies for minimizing metals in the environment. BC

IPNI Science Award is Available to Scientists in 2012

Each year, IPNI offers the IPNI Science Award to recognize and promote distinguished contributions by scientists. The Award is intended to recognize outstanding achievements in research, extension, or education, with focus on efficient management of plant nutrients and their positive interaction in fully integrated crop production that enhances yield potential. Such systems improve net returns, lower unit costs of production, and maintain or improve environmental quality.

The Award requires that a nomination form (no self-nomination) and supporting letters be received at IPNI Headquarters by September 30, 2012. The recipient is selected by a committee of noted international authorities. More information about past winners of this award, plus details on qualifications and requirements are available from the headquarters or regional offices of IPNI, or can be found at the IPNI website: >www.ipni.net/awards<. BC



Nutrient Management for High Citrus Fruit Yield in Tropical Soils

By Dirceu Mattos Junior, José Antônio Quaggio, Heitor Cantarella, Rodrigo Marcelli Boaretto, and Fernando César Bachiega Zambrosi

Current recommendations for nutrient management of citrus in tropical conditions are summarized based on the use of soil and leaf analyses, fruit yield, and characteristics of tree varieties commercially grown in Brazil.

Citrus fertilizer recommendations in Brazil largely began as adaptations of scientific information and fertilizer recommendations available in Florida and California. However, inherent differences between varieties and soils (i.e. acidic, low fertility, high P fixation) all pointed to the need for a regionally-adapted approach.

Since the 1980s, the Instituto Agronômico of Campinas (IAC) has worked to develop methods for simultaneously extracting P, Ca, Mg, and K. Extensive research on liming and fertilization has demonstrated the importance of correcting soil acidity. Subsequent work revealed the critical importance of Ca and Mg in tropical soils and their effects on citrus production and fruit quality (Quaggio et al., 1992a, b). Calibration curves for P and K have allowed estimation of concentrations of soil nutrients, above which no increase in fruit yield is expected (Quaggio et al., 1996, 1998). Mathematical models fitted to these data, allowed the concept of economy to be introduced to the fertilizer recommendations, considering soil and leaf analysis as criteria for assessing soil N availability, and fruit yield as an index of nutritional balance in citrus orchards (Cantarella et al., 1992). Scientific contributions on the effects of fertilization on fruit quality have been incorporated into these recommendations (Quaggio et al., 2005). More recently, with the significant increase in the area of citrus production under irrigation, studies on the efficiency of fertigated systems in tropical soils have also been developed.

Soil Analysis Guidelines

Guidelines for the interpretation of soil macro- and micronutrients fertility specific to citrus are provided in **Tables 1** and **2**. As a general recommendation, citrus growers should maintain soil levels for nutrients and base saturation within the adequate ranges, thus preventing deficiencies or excesses, since both limit the productivity and quality of fruits.

Leaf Analysis Guidelines

Citrus stores significant amounts of nutrients in tree biomass, part of which is available to be redistributed mainly to developing organs such as leaves and fruits (Mattos Jr. et al., 2003b). For this reason, leaf analysis is a useful tool to complement the analysis of soil fertility and also to assess the nutritional balance of citrus plants. Moreover, in the case of N, where methods of soil analysis lack consistency in diagnosis, citrus leaf N analysis has been used as a criterion for evaluating its availability (Quaggio et al., 1998).

Guidelines used for interpretation of leaf analysis are provided in **Table 3**. Orchard fertilization programs should

Common abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Ca = calcium; Mg = magnesium; B = boron; Cu = copper; Fe = iron; Mn = manganese; Zn = zinc; Mo = molybdenum; Al = aluminum.

Table 1. Guidelines for interpretation of soil analysis for macronutrients and base saturation in the topsoil of citrus orchards.

Interpretation class	P-resin, mg/dm^3	exch-K, mmol$_c$/dm^3	Mg, mmol$_c$/dm^3	Base saturation, %
Very low	<6	<0.8	<2	<25
Low	6-12	0.8-1.5	2-4	25-50
Optimum	13-30	1.6-3.0	5-9	51-70
High	>30	>3.0	>9	>70

Quaggio et al. (2010).

Table 2. Guidelines for interpretation of soil analysis for micronutrients in the topsoil of citrus orchards.

	B	Cu	Mn	Zn
Interpretation class†	- - - - - -	- - - mg/dm^3 - - -	- - - - - -	
Low	<0.6	<2.0	<3.0	<2.0
Optimum	0.6-1.0	2.0-5.0	3.0-6.0	2.0-5.0
High	>1.0	>5.0	>6.0	>5.0

†B extracted with hot water; Cu, Mn, and Zn extracted with DTPA.
Quaggio et al. (2010).

Table 3. Guidelines for interpretation of orange tree leaf analysis based on 4 to 6-month old spring flush leaves from fruiting terminals.

Nutrient	Low	Optimum	High
	- - - - - -	- - - g/kg - - -	- - - - - -
N	<23	23-27	>30
P	<1.2	1.2-1.6	>2.0
K	<10	10-15	>20
Ca	<35	35-45	>50
Mg	<3.0	3.0-4.0	>5.0
S	<2.0	2.0-3.0	>5.0
	- - - - - -	- - - mg/kg - - -	- - - - - -
B	<80	80-160	>160
Cu	<10	10-20	>20
Fe	<49	50-120	>200
Mn	<34	35-50	>100
Zn	<34	35-50	>100
Mo	<2	2-10	>10

Quaggio et al. (2010).

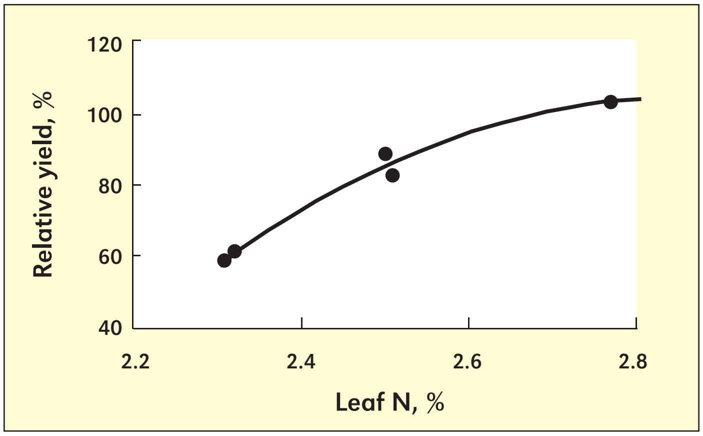


Figure 1. Response of citrus fruit yield in relation to leaf N content (Quaggio et al., 1998).

also be adjusted so that the leaf nutrient concentrations are maintained within the optimum range.

Soil Liming

Soil acidity is recognized as a major factor of low crop yields due to Al toxicity, Mn toxicity in some species, low levels of Ca and Mg, and for reducing the availability of other nutrients such as P. The main causes of soil acidification of citrus orchards in the tropics include continued use of acidifying N fertilizers, the use of fertigation, and pest control largely based on forms of elemental S.

Much of the response of citrus to lime is due to the high demand of Ca by trees (Mattos Jr. et al., 2003b). Citrus also demand significant amounts of Mg commonly supplied as dolomitic limestone. The need for lime is calculated based on an established calibration curve. The goal is to raise the base saturation (V) to 70% in the topsoil (0 to 20 cm depth), determined at pH 5.5 ($CaCl_2$ 0.01 mol/L) (Quaggio et al., 1992b). It is also recommended to manage lime application so levels of Mg in the soil are raised and maintained to a minimum of 5, or ideally 9 $mmol_c/dm^3$ (Quaggio et al., 1992a). The calculation of lime requirement is made by the following formula:

Lime (t/ha) = CEC (BS_2 - BS_1)/10 ECCE

where:

CEC = Soil cation exchange capacity, $mmol_c/dm^3$;

BS_1 = Current soil base saturation (%), 0 to 20 cm depth layer;

BS_2 = Soil base saturation recommended for citrus, equal to 70%, and

ECCE = Effective Calcium Carbonate Equivalent (%) based on the combined effect of chemical purity and fineness of grind of limestone applied.

The evaluation of soil acidity should be a routine practice within the management program of an orchard. Fertilizers in citrus are generally applied in bands that extend from under the tree to a just beyond the tree line. Thus the application of lime should also be applied in larger amounts in these locations.

Fertilizer Application

The recommendations of N, P and K fertilizer rates vary with orchard age (i.e. planting, young trees <5-years-old, and

Brazil is the world leader in the production of citrus, with an annual volume of 18 to 20 million t of fruit, or 20% of the world's total.

mature trees), citrus fruit type, rootstock, and the quality and market destination of the fruit (i.e. fresh or industrial). Leaf N content has proven to be a good indicator to recommend N fertilizer rates (**Figure 1**). Orange and mandarin response to N fertilization is lowest for foliar N concentrations above 2.8% (Quaggio et al., 1998; Mattos Jr. et al., 2004).

Since citrus trees store a large amount of N that can be easily redistributed to developing organs such as leaves and fruit, a reduction of the N fertilization may not affect fruit yield immediately. However, when leaf N levels are below those recommended, trees may suffer from gradual reduction in growth, which consequently will lead to losses in fruit production in subsequent years. The lack of N, or excess, affects size and quality of fruits (Quaggio et al., 2006a). High doses of N increase the number of fruits on the tree at the expense of fruit size. Fertilization with K also affects the size of the fruit, but excessive amounts can cause production losses largely due to an imbalance created with leaf Ca and Mg (Mattos Jr. et al., 2004). Furthermore, management of N fertilizers is important to ensure its efficient use in the production system. Urea, the most common source of N in Brazil, is subject to higher losses through volatilization of ammonia (NH_3) if no incorporation (mechanical or irrigation/rainfall) occurs. Volatilization losses may vary from 15 to 45% of N applied to the soil surface (Cantarella et al., 2003; Mattos Jr. et al., 2003b).

For P and K, calibrations of soil analysis based on extraction of nutrients with ion exchange resins are provided in **Figure 2**. The critical level for soil K availability is similar to that used for annual crops (2.0 $mmol_c/dm^3$), but for P the critical level for citrus is lower (18 to 20 mg/dm^3).

Fertilization of mature orange orchards should be conducted in the rainy season based on the recommendation guidelines presented in **Table 4**, because the demand for nutrients for citrus is highest in early spring, when vegetative growth is more intense, and extends until early fall, when nutrient reserves in the trees must be maximum to ensure optimum flowering and fruit set (Bustan and Goldschmidt, 1998). The application of N and K in 3 or 4 splits during the year increases fertilizer efficiency by reducing losses of soil nutrients with water drainage, which occurs mainly in sandy soils, and favors proper timing of nutrient supply at different

Table 4. Fertilizer recommendations for mature orange trees based on soil and leaf analyses, and fruit production classes.

Production class, t/ha	Leaf N, g/kg			P-resin, mg/dm^3				Exch-K, mmol$_c$/dm^3			
	<23	23-27	>27	<5	6-12	13-30	>30	<0.7	0.8-1.5	1.6-3.0	>3.0
	N, kg/ha			P_2O_5, kg/ha				K_2O, kg/ha			
<20	120	80	70	80	60	40	0	80	60	40	0
21 - 30	140	120	90	100	80	60	0	120	100	60	0
31 - 40	200	160	130	120	100	80	0	140	120	80	40
41 - 50	220	200	160	140	120	100	0	180	140	100	50
>50	240	220	180	160	140	120	0	200	160	120	60

stages of development of citrus (flowering to fruit maturation). It is recommended to apply 30 to 40% of N and K at flowering.

Fertigation

The area under citrus irrigation in São Paulo, Brazil has significantly increased in recent years, with most of it under drip irrigation. Fertigation is a technique that allows the application of fertilizers to plants through irrigation water. In this system one can lower the dose of fertilizer application with a consequent increase in the number of applications.

When nutrients are supplied with irrigation water, efficiency of nutrient absorption is increased because of more uniform distribution of fertilizers and the possibility to fine-tune the application of nutrients to the demands of trees in different phenological stages (Alva et al., 2008). Results of research in tropical soils have shown that citrus fertilizer efficiency increases up to 25% with drip irrigation compared to conventional, granular application (Quaggio et al., 2006b). Thus, in drip-fertigated orchards, rates of N and K can be reduced by up to 20% (**Table 4**). As fertilizers in drip fertigation are applied in a localized form, there is greater concentration of anions and cations in soil solution in relation to conditions found with granular applications. Therefore, fertigated orchards present greater potential for nutrient losses by leaching and for soil acidification. In tropical soil conditions, phosphoric acid is not recommended as a source of P.

Micronutrients

Foliar fertilization has been the most important practice used to apply micronutrients in citrus, not only because the amounts required are small, but also to avoid adsorption of metal elements to soil colloids, which reduces the availability of metal micronutrients to the plants. The application of B to citrus should preferably be made to the soil (Boaretto et al., 2011). However, the addition of the micronutrient to NPK mixtures often causes problems of segregation, because of the difficulty of obtaining an efficient granulated source of B. Therefore, it is most practical and efficient to apply boric acid dissolved with herbicides. Depending on the rootstock, 2 to 3 kg B/ha is recommended regardless of of the orchard's age.

Micronutrients such as Mn, Zn, and B have low mobility in phloem (Embleton et al. 1965; Boaretto et al., 2004, 2008). Therefore, general recommendations for foliar application to citrus are to prepare mixtures of salts and urea (5 g/L), in the concentrations (mg/L) of Zn (500 to 1,000), Mn (300 to 700), B (200 to 300), and Cu (600 to 1,000). Quantities of the fertilizer products vary with the type of salt used (i.e. chloride, nitrate and sulfate).

Foliar applications should be made in the spring and summer when leaves are young and have a poorly developed cuticle. This facilitates absorption and supply to developing organs. BC

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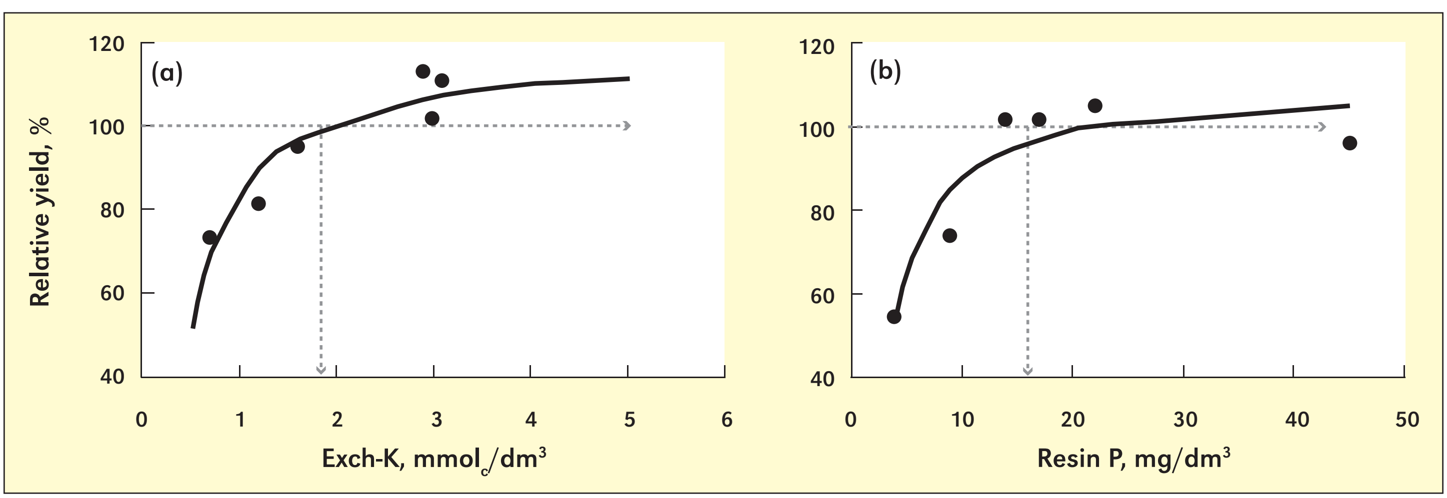

Figure 2. Calibration curve for relative production of citrus in relation to the contents of exchangeable-K (a) and P-resin (b) in the soil. (Quaggio et al., 1998).

This article was originally published in the IPNI Brazil newsletter "*Informações Agronômicas*". The article was adapted and translated to *Better Crops* by Dr. Dirceu Mattos Junior, Researcher at Instituto Agronômico (IAC) and Dr. Luís I. Prochnow, IPNI Brazil Program Director.

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São Paulo State has approximately 80% of the production of oranges in Brazil within an area of 550,000 ha. This production is intended primarily to produce concentrated orange juice.

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11th International Conference on Precision Agriculture Set for July 15-18

The International Society of Precision Agriculture (ISPA) is organizing the 11th International Conference on Precision Agriculture (ICPA) to be held at the Hyatt Regency in Indianapolis, Indiana, USA from July 15th to July 18th, 2012.

Precision agricultural techniques, technologies, and its applications continue to grow across the globe and so does the precision agricultural community. The 11th ICPA is envisioned to be the largest ever with over 600 attendees anticipated from all over the U.S. and from over 50 other countries. The 11th ICPA will highlight significant research and applications in precision agriculture, and will showcase emerging technologies and information management. The conference will offer oral and poster presentations, exhibits, and opportunities for discussion and exchange of information in various aspects of precision agriculture.

IPNI will once again be organizing a dedicated session for practitioners. The "Precision A to Z" track will offer practical advice and training from international authorities on key topics of precision agriculture for producers and professionals. Special registration rates are available for A to Z participants. Registration and other information for the conference can be found at www.ispag.org/icpa. BC

Eros Francisco (Brazil) and Sudarshan Dutta (South Asia) to Join Staff of IPNI as Deputy Directors

The International Plant Nutrition Institute (IPNI) is pleased to announce the addition of two new scientific staff to existing regional programs.

Dr. Eros A.B. Francisco is joining as Deputy Director for the Brazil Program, where he will be located in Rondonópolis, Mato Grosso, and will have primary responsibility for the mid-west region of the Cerrado as of April 1, 2012.

"This announcement marks a significant milestone for our organization as we place our third scientific staff member within the Brazil Program," said IPNI President Dr. Terry Roberts. "Our Board of Directors strongly supports the expansion of our presence in Brazil and Dr. Francisco's appointment within the heart of the Cerrado will accomplish much to support our goal of sustained improvement in nutrient use in Brazil."

Dr. Francisco, a native of Rondonópolis, received his B.Sc. (1999) and M.Sc. (2003) from the University of São Paulo. His Ph.D. was completed in 2006 from the Department of Soil and Plant Nutrition, University of São Paulo, where he examined the potential for aluminum phosphates as an alternative source of P to rice.

On completion of his Ph.D., Dr. Francisco worked with the National Institute for Colonization and Land Reform, providing technical support to farmers related to crop production. He has held teaching positions both as Professor of Agronomy at the Superior College Union of Rondonópolis, as well as Professor of Soil Conservation and Fertility, Pasture Management, and Experimental Techniques with Animals at the Exact and Natural Sciences Institute, Federal University of Mato Grosso.

Most recently, Dr. Francisco has been Research Coordinator for the Fertilization Monitoring Program, and Leader of the Applied Research Program, at the Mato Grosso Research Foundation. Selected highlights from this current research program include: evaluating the effect of crop rotation on yield, crop management, nutrient cycling, and soil physiochemical properties, in no-till grain and fiber cropping systems; optimal N, P, and K fertilization for cotton under ultra narrow rows; long-term evaluation of N rate and "ecological intensification" concepts for maize; and testing agronomic efficiency of fertilizers treated with polymers for slow release, ammonia volatilization inhibitors, nitrification inhibitors, and elemental S.

Dr. Francisco's highly applied field research program has allowed him to become a valued extension resource to farmers and has produced numerous publications within peer-reviewed journals and books.

Dr. Sudarshan Dutta is joining IPNI as Deputy Director for the South Asia Program. Based in Kolkata, West Bengal, Dr. Dutta will be responsible for the East Zone of the South Asia Program. Starting May 1, 2012, his region will cover the Indian states of Chhattisgarh, Jharkhand, Bihar, West Bengal, Assam, Arunachal Pradesh, Nagaland, Manipur, Mizoram, Tripura, Meghalaya, Sikkim, as well as Bangladesh. Dr. Dutta is filling the Deputy Director position that was vacated by Dr. Harmandeep Singh Khurana, who is now the International Agronomic and Technical Support Specialist based in the IPNI Canada office located in Saskatoon, Canada.

Dr. Eros A.B. Francisco

Dr. Sudarshan Dutta

"Dr. Dutta is a valuable addition to our scientific staff, and IPNI will benefit greatly from his strong training in soil chemistry and environmental assessment," said IPNI President Dr. Terry Roberts. "We welcome Sudarshan to our staff as we are confident he will make an outstanding contribution towards our Program goals for South Asia."

Dr. Dutta received his B.Sc. in Soil Science in 2003 from the State Agricultural University (Bidhan Chandra Krishi Viswavidyalaya), in West Bengal. He completed his M.Sc. in 2005 from Punjab Agricultural University, where he examined sorption and desorption behaviors of lead in different soils of India. Dr. Dutta obtained his Ph.D. in 2011 from the University of Delaware. His dissertation title was "Transport of free and conjugated estrogens in runoff from agricultural soils receiving poultry manure: A field and watershed scale evaluation."

Since his completion of his Ph.D., Dr. Dutta continued his work at the University of Delaware as a Post Doctoral Research Associate within the Watershed Hydrochemistry group where he has made a significant contribution to the understanding of the fate and transport of nutrients (nitrogen and phosphorus), trace elements (arsenic, copper, and zinc), and emerging contaminants including steroidal hormones, antibiotics, and their degraded byproducts within different runoff components of agricultural watersheds. Dr. Dutta's research has also involved quantifying exports of dissolved organic matter from the Fair Hill Natural Resource Management Area (NRMA)—a forested watershed in Maryland.

His research has generated a number of peer-reviewed journal articles and guest lecture invitations at the undergraduate and graduate student level. Dr. Dutta's research interest for South Asia include the implementation of regionally appropriate management practices supportive of 4R Nutrient Stewardship, soil conservation, and sustainable agricultural. BC

Common Abbreviations and Notes: N = nitrogen; P = phosphorus; K = potassium; S = sulfur.

Cold Temperatures Did Not Remove the Risk of Ammonia Loss from Surface-Applied Urea

By Richard Engel, Clain Jones, and Tom Jensen

New field research in Montana found greater than expected NH_3 losses from surface-applied urea following applications to cold soil with temperature < 5°C (41°F), including soils covered with a modest snowpack.

Surface application of N fertilizer, in particular urea, is a common management practice for dryland producers growing winter wheat in Montana and other portions of the semiarid northern Great Plains. Seeding usually occurs in mid- to late-September depending on weather conditions, then N is broadcast applied during the late fall, or winter if the snowpack is shallow (e.g. ≤ 15 cm), or early spring as long as fields will allow spreading equipment to drive on the surface without causing ruts. This is usually on cold soils (e.g. < 5°C or 41°F) that are either dry at the surface, frozen, or covered with a modest snowpack as described above. The practice of fertilizing fields in a separate operation is done primarily to expedite seeding operations. Although most modern air-seeders, are capable of side-banding N fertilizer below the soil surface where it is less susceptible to volatilization, many Great Plains growers will not utilize this practice as it slows planting operations. This is significant because individual farmers may need to seed 1,000 ha, or more, of winter wheat over a short interval of time resulting in considerable time constraints. In addition, warmer soil conditions at seeding allow the urea to be hydrolyzed and the resulting NH_4^+ converted to NO_3^- during the fall. The resulting NO_3^- is susceptible to denitrification if saturated soil conditions occur at snowmelt the following spring.

Volatilization risks associated with surface-applied urea have been assumed to be minimal if applications were made during cold weather conditions. This opinion is founded, in part, on research and extension literature that often characterizes NH_3 losses or risks as being greater at warm temperatures, and by inference, small at cold temperatures. Numerous studies have investigated and reported on NH_3 volatilization from surface-applied urea; however, we know of no study that has specifically targeted its measurement from cold soil with temperatures < 5°C. In 2008 we began a study that focused on quantifying NH_3 losses from surface-applications of urea and NBPT-coated urea performed during late-fall to early spring. The purpose of this article is to share a portion of the results obtained from this project. Ammonia volatilization losses were quantified using a micrometeorological mass-balance approach with circular plots (40 m dia.), a center mast, and samplers (Leuning et al., 1985) that provided for continuous measurement of NH_3 losses. In all trials urea was surface broadcast applied to wheat fields at rate of 100 kg N/ha. Urea was treated with NBPT (1 g/kg) using a liquid Agrotain™ formulation. Ammonia losses were followed over 8 to 10 wks by exchanging the samplers approximately once per week (see Engel et al., 2011 for details on gas sampling methodology and NH_3 loss calculations).

Ammonia Losses from Urea

Urea was surface applied to soils with temperatures < 5°C in eight campaigns. The total cumulative NH_3 loss, expressed as a percentage of the applied N rate (100 kg N/ha), averaged 26.3% for these trials but was quite variable among sites (**Table 1**). The largest cumulative NH_3 loss, 44.1% of the applied N, occurred during Campaign 10, which was conducted on a Brocko silt loam (pH 8.4) soil. The total cumulative NH_3 loss exceeded 30% of the applied N in three trials conducted on acidic soils, including Telstad–Joplin loam (pH 5.5, Campaigns 3 and 4), and Phillips–Elloam clay loam (pH 6.4, Campaign 5). A commonality of all large NH_3 loss campaigns (> 30% of applied N) was that fertilizer applications were made to a high-water-content soil surface that resulted in the dissolution of urea granules. Precipitation events that followed were ≤ 5 mm and scattered at least through the first 30 d after fertilization. Conversely, comparatively small NH_3 losses (i.e. < 10% of applied N) were observed during Campaigns 1 and 11. These trials were characterized by urea applications to dry

Common abbreviations and notes: N = nitrogen; NH_3 = ammonia; NH_4^+ = ammonium; NO_3^- = nitrate; NBPT = N- (n-butyl) thiophosphoric triamide; θv = volumetric soil water content

Table 1. Summary of cumulative NH_3 losses from urea and NBPT-coated urea (first week, campaign total) following applications to cold soils, and average soil temperature (1 cm depth) during the first week post-fertilization.

				Cumulative NH_3 loss			
			Soil temperature (1 cm depth)	Urea		NBPT-urea	
		Fertilization		1 wk	8 or 10 wks	1 wk	8 or 10 wks
Campaign	Location	date	°C	% applied			
1	West Havre	3, Apr. 2008	4.9	0.0	8.4	0.0	4.4
3	North Havre	14, Nov. 2008	0.8	12.3	31.3	0.5	3.8
4	North Havre	25, Mar. 2009	-0.7	11.5	35.6	0.8	18.0
5	West Havre	26, Mar. 2009	1.2	22.4	39.9	1.5	18.1
9	Willow Creek	27, Jan. 2010	-2.1	0.2	24.3	0.2	9.3
10	Willow Creek	26, Feb. 2010	0.9	4.9	44.1	0.2	11.9
11	West Havre	29, Mar. 2010	3.5	1.9	6.3	0.1	1.7
16	Denton	2, Mar. 2011	-5.7	1.7	20.7	0.2	10.1

Field site near Havre, Montana was covered with a trace of snow on the date of fertilization (March 26, 2009) for Campaign 5. Urea granules on frozen soil surface within 1 hr after application are beginning to dissolve and melt snow.

soil surfaces followed by a large precipitation event (> 18 mm).

Many studies on NH_3 volatilization from fertilizers have noted that large NH_3 losses are associated with an initially wet surface soil followed by several days of slow drying with little or no precipitation; and that N losses from urea are mitigated when sufficient rain or irrigation, typically 13 to 25 mm, occurred to move the N into the soil profile (Hargrove, 1988). Our results are consistent with this review; however, they are unique in that we found cold soil temperatures did not provide protection against realizing large NH_3 losses if the surface water content was high at the time of fertilization with little or no precipitation after application. For example, NH_3 losses > 10% of the applied N rate occurred over the first week post-fertilization at Campaigns 3, 4, and 5, even though mean daily soil temperature (1 cm) over the sampling period averaged only 0.8, -0.7, and 1.2°C, respectively. Particularly large NH_3 losses (22.4% of applied N) were observed over the first week at Campaign 5. Field conditions at the beginning of Campaign 5 were characterized by a frozen soil surface with a trace amount of snow, and a soil water content (0 to 8 cm) near saturation (θv = 50%). During the first week, no precipitation fell and the volumetric soil water content fell to 24.6%. Similarly, large cumulative NH_3 losses equivalent to 24.3 and 20.7% of applied N were observed after urea was broadcast onto to field sites with modest snowpack at Willow Creek and Denton, Montana (**Figure 1**). The period of greatest emission activity followed the disappearance of the snowpack when the surface was drying, and soil temperatures were still cold. At Willow Creek this was associated with the 4th and 5th week post-fertilization when soil temperatures averaged -1.5 and 0.5°C. At Denton, this was associated with the 2nd week post-fertilization when soil temperatures averaged 1.3°C.

Mitigation of NH_3 Loss from Urea by NBPT

The addition of the urease inhibitor NBPT to urea was effective in reducing NH_3 loss in all trials. Total cumulative NH_3 loss with NBPT averaged 9.7% of the applied N rate, a 63% reduction in volatilization compared with untreated urea. Mitigation of NH_3 volatilization from urea by NBPT has been attributed to a number of factors including a moderation of the soil pH rise that results with the production of ammonium bicarbonate (NH_4HCO_3) (Clay et al., 1990; Christianson et al., 1993); reduction in concentration of NH_4^+ in the soil solution around the fertilizer placement microsite (Christianson et al., 1993), thereby affecting the $NH_4^+{}_{(sol)} \leftrightarrow NH_{3(sol)} \leftrightarrow NH_{3(g)}$ equilibrium; and inhibition of hydrolysis thereby providing more opportunities for precipitation to infiltrate urea deeper in the soil where N is less susceptible to volatilization (Grant et al, 1996). The benefit of NBPT was typically limited to 2 weeks on acidic soils (i.e. after 2 weeks post-fertilization NH_3 losses were similar for the NBPT treated and untreated urea (**Figure 1b**). However, the benefit of NBPT persisted longer at the Willow Creek field site with a calcareous soil, suggesting that degradation of NBPT and/or its metabolites may have occurred more slowly at high pH. Although this effect has not been documented previously in the field, a lab incubation study found degradation of NBPT and its oxygen analog to occur more slowly in alkaline than acidic soils (Hendrickson and Douglass, 1993).

Implications and Management Recommendations

Commercial fertilizer applicators and growers in the semi-arid northern Great Plains have long assumed that surface-applied urea was not susceptible to large volatility losses if applications were made during cold weather months. The results from this study indicate this assumption may not be valid, and that significant losses of NH_3 from urea may occur even though applications were made to low temperature soils (< 5°C). In the semiarid northern Great Plains, fertilizer applications that occur during the late fall, winter, or very early spring will often be made to soil surfaces that are cold or frozen, high in water content, and sometimes covered with a modest snowpack. Urea applications under such conditions appear to be susceptible to volatility losses, particularly after the surface thaws and dries. To minimize volatility losses, growers should probably wait until the soil surface is sufficiently dry such that dissolution of the urea granules will not result. If a large precipitation event (> 18 mm as either rain or snow) is received within a few days after urea is applied to a dry soil surface then volatility losses will be < 10% of the application rate. The urease inhibitor, NBPT, applied at a rate of 1 g/kg urea reduced volatility losses by approximately two-thirds

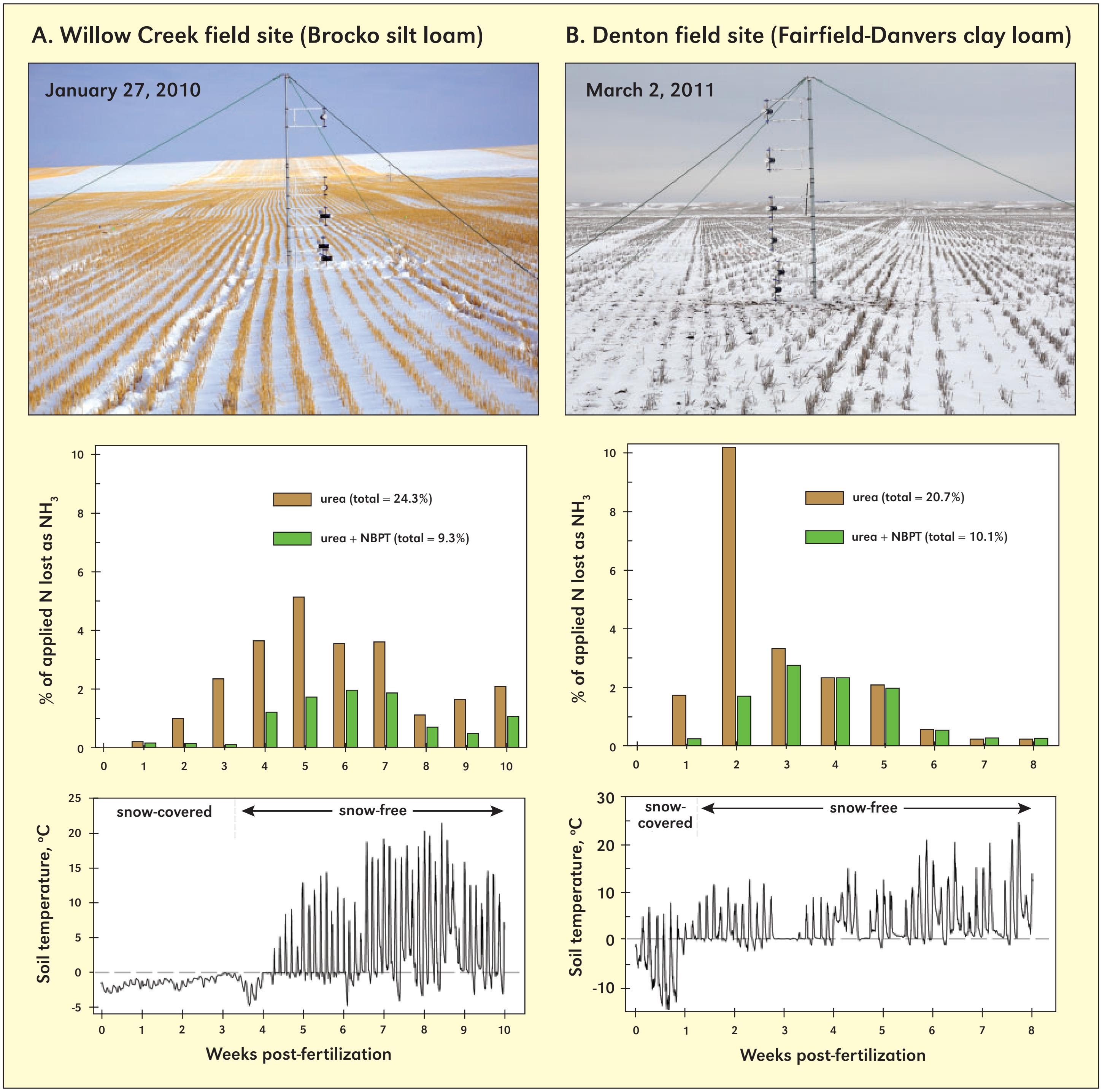

Figure 1. Urea and NBPT-urea was surface-applied (100 kg N/ha) to snow-cover fields during the winter at field sites near Willow Creek (right) and Denton (left), Montana. Ammonia N losses that resulted and soil temperature near the surface are shown below each respective photograph.

compared to untreated urea. Use of NBPT may be appropriate during cold weather months if urea is being applied to a soil surface that is wet and frozen, or covered with a modest layer of snow. Application of urea to a deep snowpack over a frozen layer of soil is not advised because of the possible movement off the field of dissolved urea in the surface runoff. BC

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Patterns of Nutrient Accumulation in 'Hass' Avocado Fruit

By Richard Rosecrance, Ben Faber, and Carol Lovatt

Synchronizing plant nutrient demand with fertilizer application increases nutrient use efficiency, is cost-effective, and protects the environment. Avocado trees were sampled during their 2-year growing cycle to determine the pattern of nutrient accumulation in the fruit as a guide for better timing of fertilizer applications.

An understanding of seasonal nutrient requirements of crops is important in order to develop best fertilizer management practices. 'Hass' avocado trees absorb nutrients according to seasonal growth patterns, and matching fertilizer applications to those patterns can maximize yields, improve fruit quality, increase nutrient uptake, and reduce the potential for nutrient loss.

Avocado fruit is unique because it remains on the tree for 15 to 18 months after spring bloom (i.e. two growing seasons) and the developing fruit is a strong sink for nutrients (**Figure 1**). Fruit N removal values in the literature range from 11 to 61 kg N/ha based on a 10 t/ha crop yield. However, little is known about the pattern of nutrient uptake into avocado fruit. This understanding is important to schedule fertilizer applications to coincide with periods of high nutrient demand, thereby maximizing nutrient use efficiency.

Research was conducted in a commercially bearing mature 'Hass' avocado orchard growing on a gravelly loam (thermic Typic Argixerolls) in Moorpark, California. Fruit samples were harvested monthly for 1 year from two different trees each month. The total fruit weight and number of fruit per tree were determined as were the concentrations of specific nutrients in the tissues of fruit.

Avocados are grown in more than 60 countries. The Hass variety (shown here) is the most common, but other locally adapted varieties are also cultivated.

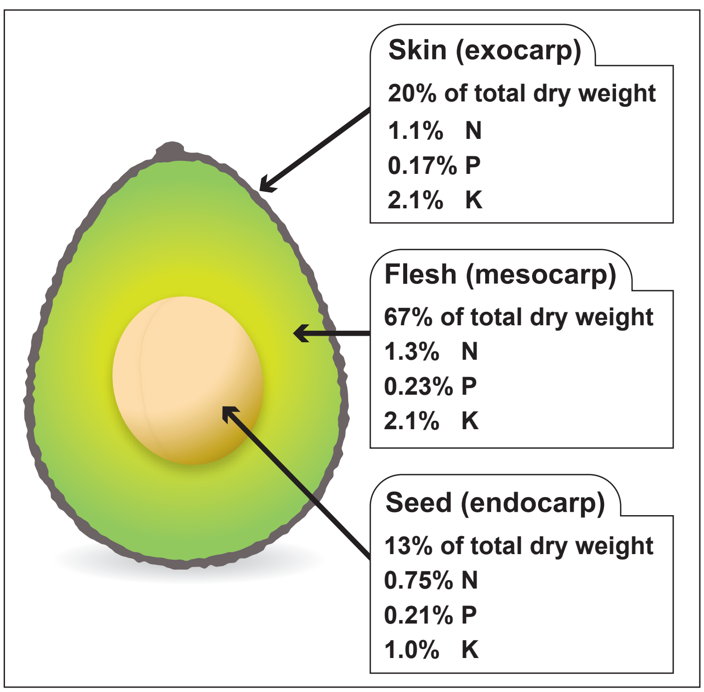

Figure 1. The dry weight and nutrient content (dry weight basis) of mature avocado fruit skin, flesh, and seed.

Common abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Mg = magnesium; Ca = calcium; B = boron.

Dry Weight and Nutrient Accumulation Patterns

Fruit dry matter accumulation followed a double sigmoid curve (**Figure 2**). Fruit growth was split evenly over the 2 years, with about half of the total fruit dry weight accumulating during the first growing season and half accumulating the following year. Dry matter accumulation ceased during the winter months (i.e. December to March). This differs from avocados growing in tropical environments where fruit growth follows a single sigmoid curve.

Similar to the dry matter growth curve, avocado fruit accumulated most nutrients in a double sigmoid pattern with nutrient uptake ceasing during the winter months (**Figure 3**).

Accumulation patterns, however, differed for the individual nutrients. Approximately 50% of the total fruit nutrient uptake for N, P, Mg, and S occurred during the first year and 50% accumulated during the second growing season. In contrast, only about 30% of the total fruit K and B accumulated during the first year, and the remaining 70% accumulated during the second growing season. In contrast to other nutrients, fruit Ca content followed a single sigmoid curve, where it increased during the first 5 months following bloom and then remained constant until fruit harvest in September the next year (**Figure 2**).

Timing Fertilizer Applications to Meet Tree Nutrient Demand

Avocado fruit accumulated the majority of nutrients between full bloom and autumn and also during the following spring. These periods of high fruit nutrient demand should coincide with timely fertilizer applications. For example,

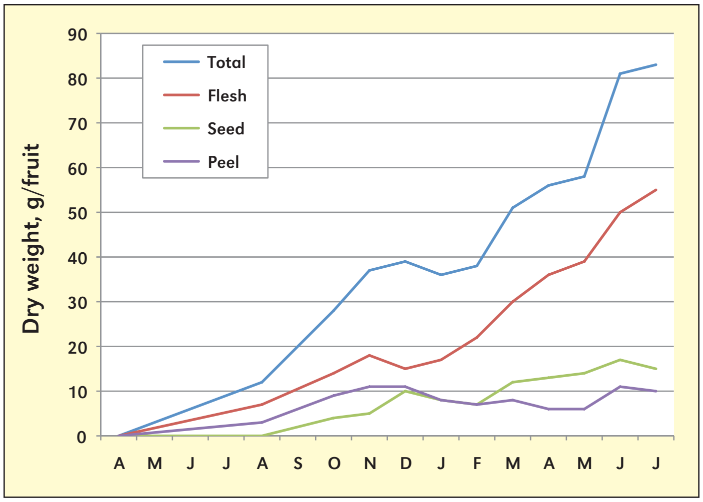

Figure 2. Dry matter accumulation in an avocado fruit from bloom to harvest.

in earlier experiments N fertilization in the spring (April) increased both fruit size and yield and reduced the severity of alternate-bearing compared with trees receiving N at any other time of the year besides April. April N fertilization appears to be critical for fruit set of the new crop, for growth of the vegetative shoot flushes, and to support fruit growth of the maturing crop.

Fertilizer applications at the very least must replace nutrients removed in fruits to avoid soil depletion. In this study, primary and secondary nutrient removal by a 10 t/ha avocado crop was (kg/ha) 22 N, 30 K, 4 P, 5 S, 1 Ca, and 3 Mg (**Table 1**). Other factors in the orchard will also influence crop nutrient removal, such as rootstock, scion cultivar, and tree age.

To synchronize fruit nutrient demand with fertilizer application, we recommend for:

N, P, Mg, S, Fe, and Zn – Apply these nutrients during the Spring growing season after full bloom and repeat again the second year during the same time period. This strategy supplies nutrients to the recently pollinated flowers as well as the maturing fruit.

K and B – These nutrients are accumulated more rapidly during the second season of fruit development. Depending on the fruit load, a higher application rate may be needed to support the maturing fruit.

Ca – Since most of the Ca was accumulated during the first year of fruit growth, an abundant supply must be available during early fruit development.

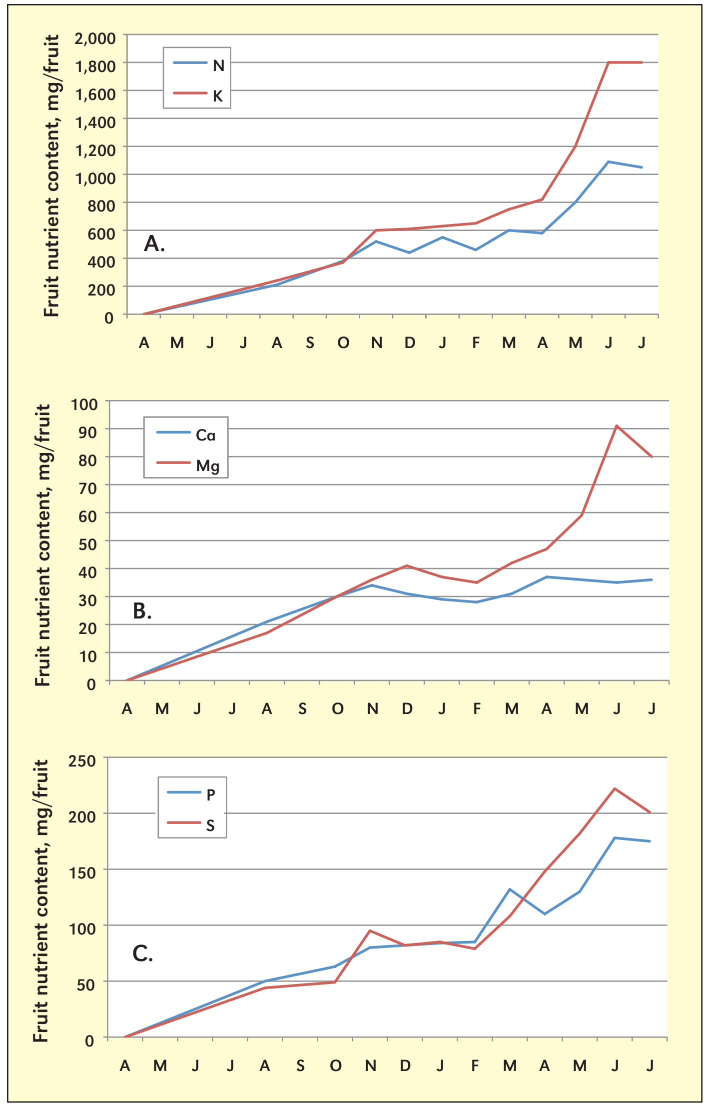

Figure 3. Accumulation of selected nutrients in 'Hass' avocado fruit from bloom to harvest. Uptake patterns are shown for N and K (A), Ca and Mg (B), and P and S (C).

Table 1. Nutrients removed from an avocado crop based on a 10 t/ha yield†.

Nutrient	This study	Other literature‡	Nutrient	This study	Other literature‡
	----------- kg/ha -----------			---------- g/ha ----------	
N	22	11 to 41	B	192	401
P	4	2 to 10	Fe	45	47 to 212
K	30	20 to 61	Zn	67	45 to 156
S	5	4 to 8	Mn	12	9 to 47
Ca	1	2 to 7	Cu	29	10 to 58
Mg	3	4 to 8			

† Calculated on a fresh weight basis.
‡ Specific literature citations are available at http://info.ipni.net/BCADDENDA.

Synchronizing the timing of fertilizer applications with plant nutrient demand is critical for the successful production of avocado fruit. It is also important to consider the right fertilizer source, rate, and placement of the added nutrients in order to meet the desired economic and environmental objectives. BC

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Nitrogen Fertilization of Nitrogen-Stressed Soybeans

By Dave Mengel, Dorivar Ruiz-Diaz, Ray Asebedo, and Tom Maxwell

Soybeans are not generally considered responsive to N fertilizer; however, there are some circumstances where this crop can benefit from addition of N. Kansas research performed several years ago and reported in this magazine showed the potential for soybean grain response to N fertilizer in high-yield irrigated conditions. This article looks at other conditions where N fertilizer can be beneficial in soybean production.

Soybeans do not normally respond to applications of N fertilizer as long as they are well nodulated with rhizobia bacteria. When soybeans are planted into ground that has no history of soybean production, or when there has been a long interval between soybean crops, adequate rhizobia may not be present for successful nodulation and N fixation. This is usually overcome by inoculating the seed with rhizobia. However, these inoculations are not always successful, and when this happens, poorly nodulated, N-deficient soybean crops can result.

In both 2009 and 2010, a number of fields planted into "virgin" soybean ground, or into returned Conservation Reserve Program (CRP) ground in north central Kansas were observed to be poorly nodulated and N-deficient even though the seed was commercially inoculated. A field study was conducted in 2009, and continued at a different location in the same area in 2010, to determine whether these poorly nodulated, N-deficient soybean crops would respond to applied N fertilizers, and if so, how much N could successfully be used.

The 2009 study was conducted on a farmer's field near Solomon, Kansas that showed noticeable N deficiency in soybean. Variety NK S39-A3 was planted (no-till) into sorghum residue from the previous year on May 20, 2009, at 140,000 seeds/A. A liquid inoculant was sprayed on the seeds as they were loaded into the planter. This field had no history of soybean production. Nitrogen fertilizer was applied on July 20, 2009, to plants displaying N deficiency symptoms at the R1 to R2 growth stages. The N was surface banded between the soybean rows in the form of urea co-granulated with a urease inhibitor (NBPT) and nitrification inhibitor (dicyandiamide). Rainfall occurred within a few hours of N application.

The 2010 study was conducted on a farmer's field near Gypsum, Kansas that had poorly nodulated, N-deficient soybean. Variety P93Y70 was planted into conventional tilled soil at 130,000 seeds/A on June 19, 2010. The seed was inoculated prior to planting. This field also had no history of soybean production. The N was broadcast-applied as urea (co-granulated with NBPT + dicyandiamide) on July 22, 2010. Rainfall did not occur until 14 days after treatments were applied.

Broad view of field plots showing impact of N fertilization of soybeans in N deficient conditions. Field had no history of soybean production. Seed was inoculated but crop was poorly nodulated.

Table 1. Effect of nitrogen fertilization on yield of N-deficient soybeans (2009-2010).

N rate, lb/A	Solomon 2009	Gypsum 2010	Average
	- - - - - - - -	Yield, bu/A	- - - - - - - -
0	28d	18c	23d
30	37c	23b	30c
60	42b	26b	33cb
90	43b	26b	34b
120	49a	29a	39a
150	N/A	29a	N/A

Means within a column followed by the same letter are not significantly different at p = 0.05.

Results

The results from both studies for 2009 and 2010 are summarized in **Table 1**. In 2009, a highly significant response to the highest N rate applied, 120 lb N/A, was obtained, with a 21 bu/A increase over the control.

Yields at Gypsum in 2010 were lower due to dry weather; however, similar trends were observed, with an 11 bu response to the first 120 lb of N/A compared to the control. There was no advantage to increasing the N rate from 120 to 150 lb/A in 2010. When averaged across years, the data show a clear response to N, with highest yields found at 120 lb N/A.

The data from these studies show that applying N fertilizer to poorly nodulated, N-deficient soybean can significantly enhance yield. Applying up to 120 lb N/A was effective in each of the 2 years of this study. At current fertilizer and commodity prices these responses would provide a good return on investment, even on the modest yields obtained in 2010. The results of this work were previously published in the Kansas Fertilizer Research Report (Asebedo and Mengel, 2010).

Conclusions

While N applied to N-deficient soybeans at the pod development or early pod fill stages of growth can increase yields, it should be noted that there are risks:

Leaf burn – It would be much safer to apply urea than UAN solution.

Common notes and abbreviations: N = nitrogen; NBPT = N-(n-butyl) thiophosphoric triamide.

Volatilization – Urea applied to the soil surface under warm, damp, windy conditions may volatilize if it is not moved into the soil by rainfall. This risk can be minimized by having the urea treated with NBPT.

Dry weather after application – If it does not rain after application, the N may not get down into the soil in time to benefit the crop.

Plant damage during the application process – At this time of year, making a fertilizer application with ground equipment could damage some of the plants. Whether the benefits would outweigh the amount of plant damage is a case-by-case judgment call.

This article has reported on one set of conditions where soybeans have the potential to respond to N fertilization. It should also be noted that irrigated soybeans with high yield potential may respond to N applications, even if they are not N deficient. Research was conducted several years ago at Kansas State on late-season application of N to soybeans (Lamond and Wesley, 2001). This research was on irrigated soybeans with high yield potential, and the plants were not showing N deficiency at the time of application. Lamond applied 20 and 40 lb N/A to the beans at the R3 stage, using UAN, ammonium nitrate, urea, and urea + NBPT. The N increased yields at most locations. The yield increases ranged from about 6 to 10 bu/A—or about 5 to 10%. The high rate (40 lb N/A) of UAN caused severe leaf burn. It was concluded that late-season supplemental N at a rate of 20 lb/A should be applied to irrigated soybeans with high yield potential at the R3 growth stage. BC

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Close-up of field plot showing N deficiency where no N was applied to soybeans (top) and the effect of N application to soybeans (bottom). Field had no history of soybean production. Seed was inoculated but crop was poorly nodulated.

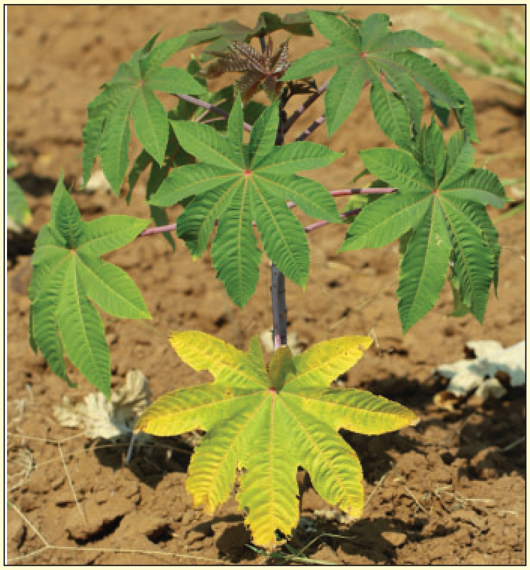
Winners of IPNI 2011 Crop Nutrient Deficiency Photo Contest

IPNI has announced the winners of our 2011 Crop Nutrient Deficiency Photo Contest. "Our response this past year has been terrific as the diversity and quality of images submitted seems to improve with each year," noted IPNI President Dr. Terry Roberts. "Our contest has evolved into a world-wide forum for all with a keen eye and access to growing crops to share their unique examples of crop nutrient deficiency and we are very pleased to continue to support this effort."

As has become the custom, our judges were challenged with the task of choosing the winners of each category by evaluating the overall visual quality of each image along with any supporting data provided. IPNI extends our congratulations to all winners and we thank all entrants for submitting images to our annual contest maintained on the web at www.ipni.net/photocontest. We look forward to collecting your entries in 2012!

Best Overall Image

Grand Prize (USD 200): Boron (B) Deficiency in Oil Palm. Jose Alvaro Cristancho Rodriguez, Postdoctoral Researcher in Soil and Water Management, Cenipalma, Colombia, captured this image of a 2-year old oil palm hybrid crop (*Elaeis oleífera x Elaeis guineensis*, Jacq.) in the Altamira estate, Casanare, Colombia. Wrinkled leaflets/frond characterize this B deficiency. The B content in frond 9 was 10 mg/kg and in frond 17th was 12 mg/kg. This acute B deficiency could be a result of the planting material and also because of liming applications and high rates of N applied in 2009 and 2010.



Nitrogen Category

1st Prize (USD 150): N-Deficient Castor. Dr. Prakash Kumar, Agricultural Research Officer, Department of Agriculture, Government of Rajasthan, India, took this close-up of N deficiency in castor (*Ricinus communis* Linn.) in Dodua, District Sirohi, Rajasthan. The soil had 136 kg/ha of N. Thirty (30) days after the crop was sown, it's older leaves turned pale green or yellow while younger leaves remained green.

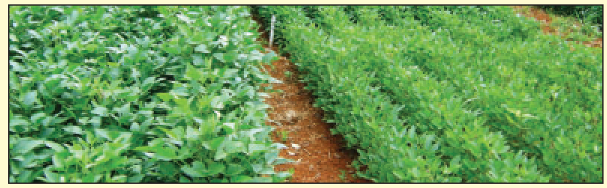
Runner-up (USD 75): N-Deficient Wheat. Sala Florin, Banat's University of Agricultural Sciences and Veterinary Medicine, Timisoara, Romania, provided an interesting example on N deficiency in wheat—taken at the end of tillering and the beginning of stem elongation stage. This field was located in Voiteg, Romania, and was fertilized with liquid swine manure (2 m applicator width) in the fall season, which was incorporated at a depth of 12 to 15 cm. While moving the applicator to the edge of the plot, a portion of the field did not receive any manure and N deficiency occurred in the spring season.

Abbreviations and notes: Mn = manganese; N = nitrogen; P = phosphorus; K = potassium; Fe = iron; B = boron; C = carbon; ppm = parts per million.

Phosphorus Category

1st Prize (USD 150): P-Deficient Hybrid Maize. Dr. Ch Srinivasa Rao, Principal Scientist (Soil Science), Central Research Institute for Dryland Agriculture, Hyderabad, India, submitted this conspicuous example of P deficiency in a hybrid maize crop at seed-filling stage. Symptoms of P deficiency included purple pigmentation, stunted growth, reduced leaf size, and small cobs, and led to complete failure of maize crop. The soil was coarse-textured (an Alfisol), with 12% clay content, 3.2 g/kg organic C and 4.8 kg/ha (low) Bray-P. Leaf tissue analysis also registered a lower value of 0.12% P.

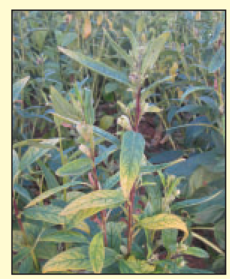
Runner-Up (USD 75): P-Deficient Soybean. Luiz Antônio Zänao Júnior, Agricultural Resaerch Institute of Paraná, Brazil, shot this close-up showing P deficiency in soybean at flowering (R2) stage. The photo shows P deficiency through a side-by-side comparison of a plot that received 120 kg/ha of P_2O_5 (left) and a P-omission plot (right). In the P omission plot, the soil had low available P (0.77 mg/kg - Mehlich-1), and leaf analysis also indicated a low P content (0.1%). P-deficient soybean plants had small leaflets and showed stunted growth.



Potassium Category

1st Prize (USD 150): K-Deficient Coconut. Dr. Jeena Mathew, Scientist, Soil Science, Central Plantation Crops Research Institute, Regional Station, Kayamkulam, Alleppy, Kerala, India, submitted this classic example of K deficiency in 30-yr old oil palm (cv. West Cost Tall) grown in a coastal sandy loam soil with pH 4.2 to 4.5. The shot was taken at a farmer's field in Edava Panchayath, Trivandrum district, Kerala. Symptoms of K deficiency included yellowing in older leaves progressing from the margin towards the base. Tips of the leaflet were withered and necrotic, the midrib was green, but the leaves had an orangish tinge with some leaves having a scorched appearance.

Runner-up (USD 75): K-Deficient Sesame. P. Jeyakumar, Associate Professor, Tamil Nadu Agricultural University, Tamil Nadu, India, shot this characteristic example of K deficiency in sesame (Gingelly, cv. TNAU Sesame TMV 3) wherein K-deficient plants exhibited yellowing of leaf tips followed by drying in matured leaves. Under acute deficiency, the younger leaves also showed yellowing and tip drying. The capsules became small and slender. Potassium content in the affected plants was found to be low at 1.17%.



Other Category (Secondary and Micronutrients)

1st Prize (USD 150): Mn-Deficient. Basil Matthew Stewart, E.E. Muir & Sons, Victoria, Australia, provided this example of Mn deficiency in hydroponically grown basil at harvest stage. Symptoms appeared as a yellowing of tissue in-between veins, visible on upper, middle, and lower leaves. Hydroponic feed solution analysis revealed a Mn level of 0.17 ppm (ideally it should be >0.5 ppm) and petiole sap analysis found a Mn level of 0.8 ppm (ideally it should be >2.0 ppm). The supply of Mn was increased by 100% and new growth showed no signs of the deficiency.

Runner-up (USD 75): Fe-Deficient Guava. P. Jeyakumar, Associate Professor, Tamil Nadu Agricultural University, Tamil Nadu, India, submitted this interesting case of Fe deficiency in a 2-year old guava (*Psidium guajava*) grown in the eastern block farm of the university. The interveinal areas of leaves appear yellow while the midrib and veins are green in color. The leaf Fe content was 65 ppm. Rapid tissue analysis also confirmed Fe deficiency.

Balanced Fertilization Promoted Yield and Quality of Waxy Maize in Chongqing

By Hongzhou He, Wei Li, and Shihua Tu

Optimal fertilizer treatment cannot only produce high yield and quality of waxy (fresh) maize, but also enhance the net income for growers. The contents of total sugar and amylopectin, which govern maize palatability, can be positively affected through optimal N and K application.

Waxy (fresh) maize has gained wide popularity across the households of China as an on-the-cob product due to its preferred taste characteristics. High market value has made this crop very lucrative for the region's growers. However, in the pursuit of high yields farmers tend to overuse N fertilizers due to a lack of information on best nutrient management practices.

A project was launched in 2008 to test the optimal (OPT) fertilizer rates and fertilizer combinations for high yielding, profitable waxy maize. Field experiments were conducted on an alluvial, sandy loam soil in Tongliang. Surface (0 to 15 cm) soil samples were collected from the field after harvesting the previous wheat crop. These samples were then analyzed by the National Laboratory of Soil Testing according to the ASI method (Portch and Hunter, 2005) (**Table 1**).

Table 1. Status of soil pH and selected nutrients from the field site in Tongliang (ASI method).

OM, g/kg	pH	NH_4-N	NO_3-N	P	K	B	Mg	Zn
		- - - - - -	- - - - - -	- - -	mg/L	- - -	- - - - - -	- - - - - -
4.4	8.1	13	37	22	29	1.1	98	2.8

Soil test results indicated that the soil was alkaline, had adequate P, B, and Zn, but was deficient in N and K. The experiment was set up in a randomized complete block design with three replications. There were four rates of N (150, 225, 300, 375 kg N/ha), P (0, 75, 150, 225 kg P_2O_5/ha), and K (0, 75, 150, 225 kg K_2O/ha), which combined to form 10 treatments (**Table 2**). The OPT NPK treatment was 300-150-150 kg N-P_2O_5-K_2O/ha. This N rate was identified by previous field experimentation while the P and K rates were determined by soil testing. Urea, SSP, and KCl were used as fertilizer sources. All P fertilizer was applied at seeding (a basal dose). Fertilizer N application was split between basal (30%) and topdress applications (i.e. 30% at the two-leaf and 40% at heading stages). Fertilizer K was split between a basal dose (50%) and a topdressing (50%) at the heading stage. Maize seeds were planted on a nurse bed in mid-February and seedlings were transplanted in early March using a plant population of 37,880 plants/ha. Maize cobs were harvested in early June and yield was recorded on a fresh weight basis. Maize kernel samples were collected from each plot, oven-dried, and analyzed for vitamin C, amino acids, total sugar, amylopectin, and prolamine.

Maize Yield

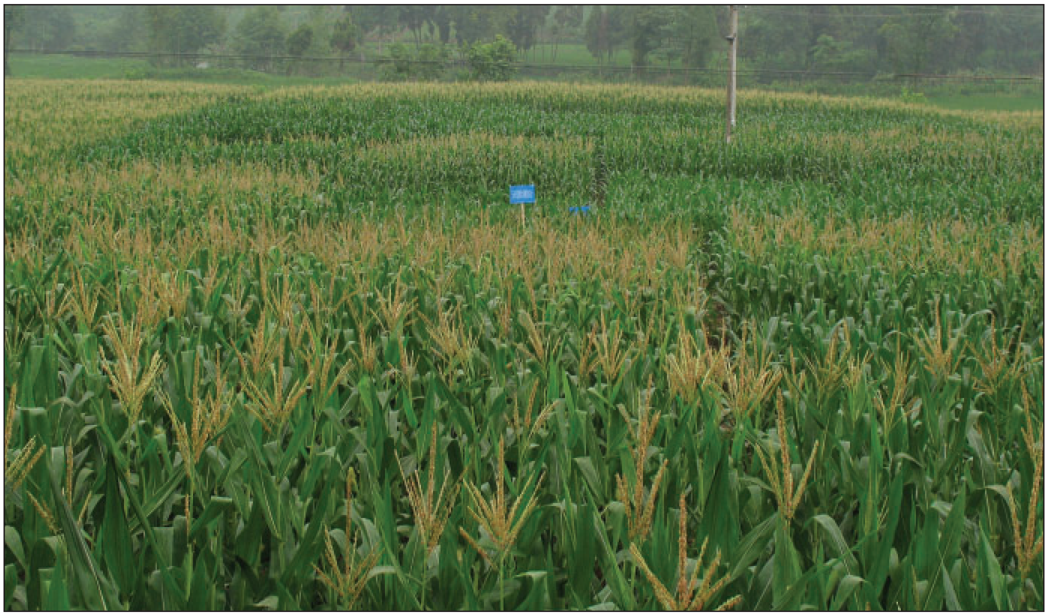
Different rates of N, P, and K fertilizers significantly affected maize yield, but the effect varied considerably between 2 years (**Table 2**). In 2008, maize yields responded significantly to all the N, P, and K rates applied, which increased with an increase in fertilizer rates and then leveled off when the fertilizer rates exceeded those used in the OPT treatment. Omission of P or K from any fertilizer program would reduce maize yield by 17 and 19%, respectively, if compared to yield under the OPT. In 2009, maize pollination was affected due to three rainfall events that occurred during the flowering stage. This resulted in higher numbers of barren ear tips and lower yields. Besides these lower yields, the yield response to fertilizer application rate was comparable. Although the relative yield of the P omission treatment did not differ between the 2 years (82.6% in 2008 and 82.5% in 2009), the omission of K lowered relative yield from 81% in 2008 to 77% in 2009. This is because soils in southern China are nearly always K responsive due to continuously removal by crops and leaching, while soil P reserves are more highly buffered from these influences (Xie et al., 1991).

Common abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; Mg = magnesium; B = boron; Zn = zinc; NH_4 = ammonium; NO_3 = nitrate; SSP = single superphosphate; KCl = potassium chloride; OM = organic matter.

Table 2. Waxy maize yields as affected by N, P, and K rate, Tongliang.

Treatment	2008 Yield[1], kg/ha	2008 Relative yield, %	2009 Yield, kg/ha	2009 Relative yield, %	Average Yield, kg/ha	Average Relative yield, %
150-150-150	15,750 b	90.7	14,882 b	89.0	15,316 b	89.9
225-150-150	16,933 a	97.5	14,630 b	87.5	15,782 b	92.6
300-150-150 (OPT)	17,367 a	100.0	16,717 a	100.0	17,042 a	100.0
375-150-150	17,100 a	98.5	14,647 b	87.6	15,873 a	93.1
300-0-150	14,350 c	82.6	13,788 c	82.5	14,069 c	82.6
300-75-150	15,550 b	89.5	14,545 b	87.0	15,048 b	88.3
300-225-150	17,367 a	100.0	14,798 b	88.5	16,082 a	94.4
300-150-0	14,050 c	80.9	12,845 d	76.8	13,448 c	78.9
300-150-75	16,067 ab	92.5	13,906 c	83.2	14,986 b	87.9
300-150-225	16,983 a	97.8	14,747 b	88.2	15,865 a	93.1

Means in each column followed by the same letter are not significantly different at p = 0.05.
[1]Fresh weight yields.



Tongliang county is a newly developed production base with 6 million ha of planting area aimed at supplying waxy maize to both rural and urban people in Chongqing city.

Maize Quality

Kernel quality parameters were obviously affected by the rate and balance of N, P, and K application (**Table 3**). Protein and vitamin C (Vc) govern the food value, while total sugar and amylopectin influence palatability. Data in Table 3 were a 2-year average of one replication of the maize experiments and thus, were insufficient for statistical analysis. However, as was found by Shi and Zhang (1994) and Shi (1995), contents of Vc and prolamine in maize seeds appeared to increase with N, P, and K rate; while percentage of total sugar declined under higher rates of N or K, they remained constant within the range of P rates tested. As with total sugar, the content of amylopectin in kernels also seemed to be influenced by NPK rate and balance.

Table 3. Waxy maize kernel quality as affected by N, P, and K rate (average of 2 years), Tongliang.

Treatment	Vc, mg/kg	Total sugar, %	Amylopectin, %	Prolamine, %
150-150-150	168.8	29.8	26.8	7.8
225-150-150	183.9	29.1	26.2	8.8
300-150-150 (OPT)	180.5	27.3	19.3	9.1
375-150-150	178.7	26.6	20.6	8.4
300-0-150	176.4	27.4	24.6	8.7
300-75-150	172.8	27.0	24.3	8.8
300-225-150	176.3	27.1	24.4	9.0
300-150-0	180.8	28.7	25.9	7.9
300-150-75	181.4	28.8	25.9	8.5
300-150-225	173.6	26.8	24.1	8.7

Economic Benefit

As is shown in **Table 4**, the profitability varied considerably with fertilizer treatment. The OPT treatment produced the highest net income of USD 2,556/ha—a good income for the region's grain growers. The differences between the OPT and the other treatments ranged between 327 to USD 755/ha. Omission of K and P resulted in the two least profitably scenarios in this study.

Table 4. Net income generated from waxy maize production as affected by N, P, and K rate, Tongliang.

Treatment	Cost of production†	Gross income	Net income
	---------------	USD/ha	---------------
150-150-150	8,055	3,488	2,229
225-150-150	8,385	3,429	2,119
300-150-150 (OPT)	8,715	3,918	2,556
375-150-150	9,045	3,433	2,020
300-0-150	7,920	3,232	1,994
300-75-150	8,242	3,409	2,121
300-225-150	9,338	3,468	2,009
300-150-0	7,740	3,011	1,801
300-150-75	8,302	3,259	1,962
300-150-225	9,428	3,456	1,983

†Cost of production includes: seed and plastic film $160/ha, labor $656/ha; N $0.67/kg, P_2O_5 $0.98/kg, K_2O $0.98/ha. Waxy maize value = $0.23/kg.

Summary

Yields of waxy maize responded significantly to N, P, and K in both years of this study, with the highest yield obtained from the selected "optimum" treatment and the lowest from treatments omitting K and P. Repeating K omission for 2 years further reduced relative yield. Among the kernel quality parameters, vitamin C and prolamine responded positively to N, P, and K and reached their maximum at the selected OPT treatment. Total sugar and amylopectin decreased as the rates of N and K increased, but were not affected by P rate. Maize kernel sweetness and/or palatability can be controlled by adjusting N and K rates. Use of the selected OPT treatment for this location resulted in both the highest yield and net income. BC

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4R Nutrient Management Practices for Potato Production in China

By Shutian Li and Jiyun Jin

In China, potato yields have been restricted by low and unbalanced nutrient input. A key measure to better tuber yield, quality, and improved nutrient use efficiency will be successful implementation of regionally-based, best nutrient management practices.

China is the world's largest potato producer. Almost two-thirds of its potato production comes from six northwestern and southwestern provinces/regions (i.e. Inner Mongolia, Gansu, Sichuan, Guizhou, Yunnan, and Chongqing city). Low fertilizer use and imbalanced nutrient application are partially responsible for low tuber yields and quality throughout. Significant area in the southwest is especially dominated by mountains and plateaus, which present complex topography and production challenges. This article presents examples of nutrient management practices needed to address the nutrient requirements of potato in China. These examples are based on the 4R Nutrient Stewardship principles that provide the right nutrient source at the right rate, time, and place (Roberts, 2007).

Nutritional Requirements

It is important to know the nutrient requirements of potato before considering any particular nutrient management strategy. These requirements can vary considerably for all nutrients based on soil test levels. In the case of P, for example, the presence of free lime at the surface can have a particular impact. Westerman (2005) reviewed potato nutrition data from the USA and Canada and found nutrient uptake to average 4.19 kg N/t, 1.26 kg P_2O_5/t, and 7.20 kg K_2O/t. Experiments in Inner Mongolia (northwest China) from 2002 to 2007 found averages of 6.03 kg N/t, 1.30 kg P_2O_5/t, and 6.18 kg K_2O/t (**Table 1**). Values for N were considerably higher than those reported by Westerman, while the P and K requirements were very similar. The difference observed for N may reflect both the severely degraded nature of soils at the Chinese field sites, and general overuse of N fertilizers in the recent past. This particular dataset found no clear differences in nutrient requirement per tonne of harvested tuber between rainfed and irrigated fields despite clear differences in final yield.

Common abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; Ca = calcium; Mg = magnesium; Mn = manganese; Fe = iron; Al = aluminum; CRU = controlled release urea; KCl = potassium chloride; KNO_3 = potassium nitrate; K_2SO_4 = potassium sulfate; SSP = single superphosphate; TSP = triple superphosphate; $MgSO_4$ = magnesium sulfate; $MgCl_2$ = magnesium chloride; DCD = dicyandiamide; NBPT = N-(n-butyl) phosphoric triamide; RMB = Chinese yuan; Currency values are in US dollars (USD).

Table 1. Nutrient requirements of rainfed and irrigated potato in northwest China.

Year	Water regime	Yield, t/ha	Nutrient uptake, kg/t			
			N	P_2O_5	K_2O	N:P_2O_5: K_2O
2002	Rainfed	11.8	7.36	1.65	6.37	1:0.22:0.87
2002	Irrigated	34.4	5.89	1.41	4.89	1:0.24:0.83
2003	Rainfed	9.6	4.23	1.37	5.45	1:0.32:1.29
2003	Irrigated	32.4	5.71	1.15	5.64	1:0.20:0.99
2004	Rainfed	14.4	6.87	1.13	5.02	1:0.16:0.73
2004	Irrigated	26.0	4.70	0.73	5.67	1:0.16:1.21
2005	Rainfed	19.3	4.79	1.23	4.18	1:0.26:0.87
2005	Irrigated	37.5	4.40	1.58	6.63	1:0.36:1.51
2006	Rainfed	14.2	5.84	1.42	6.36	1:0.24:1.09
2006	Irrigated	31.5	6.91	1.62	7.91	1:0.23:1.14
2007	Rainfed	10.3	8.04	1.09	6.55	1:0.14:0.81
2007	Irrigated	30.6	7.58	1.21	9.44	1:0.16:1.25
Average		22.7	6.03	1.30	6.18	1:0.22:1.02

Table 2. Effect of controlled-release urea (CRU) on tuber yield and N use efficiency compared with regular urea (RU), Inner Mongolia (2009 to 2011).

Treatment†	Tuber yield, t/ha	AE_N, kg tuber /kg N‡	RE_N, %§
CK	30.2 d	-	-
100% CRU	38.6 a	33.3 ab	45.3 ab
100% RU	36.4 b	24.5 bc	32.1 c
75% CRU	37.0 ab	35.6 a	52.3 a
75% RU	34.6 c	22.4 c	40.6 bc

†CK = without N; 100% CRU = recommended N applied as CRU; 100% RU = recommended N rate applied as RU.
Fertilizer N, P, and K were applied basally in all treatments.
‡AE_N = Agronomic efficiency of N. §RE_N = Recovery efficiency of N.
Means within the same column followed by the same letter are not significantly different at $p = 0.05$.

The Right Source

For N, rapidly soluble sources such as urea and ammonium bicarbonate (NH_4HCO_3) are more commonly used in China. However, slow/controlled-release N fertilizers are also used, which can contain a nitrification inhibitor (DCD) and/or urease inhibitor (NBPT), or are coated with inorganic materials (e.g. S), or an organic polymer. Slow/controlled-release N fertilizers regulate the release of fertilizer N over time, and can improve N use efficiency by synchronizing the supply of N with crop demand. They can also reduce application rates and labor costs. Slow/controlled-release N appears best suited

Table 3. Comparison of an optimum fertilizer treatment (OPT) with farmer's practice (FP) in selected potato field trials from China.

Location	Treatment	N, kg/ha	P_2O_5, kg/ha	K_2O, kg/ha	Tuber yield†, t/ha	Cost‡, USD/ha	GRF§, USD/ha
Jishishan, Gansu	OPT	120	120	150	35.4 a	314	2,479
	FP	60	30	0	29.0 b	69	2,223
Zhangjiachuan,Gansu	OPT	104	72	68	29.6 a	193	2,144
	FP	104	0	0	24.2 b	74	1,841
Wuchuan, IMAR	OPT	125	125	100	14.2 a	281	841
	FP¶	60	18	0	13.3 a	294	757
Wuchuan, IMAR	OPT	250	225	200	31.5 a	540	1,949
	FP#	141	51	0	29.6 b	853	1,485
Huzhu, Qinghai	OPT	158	75	135	17.9 a	289	1,125
	FP	240	52	90	17.2 a	290	1,069
Xining, Qinghai	OPT	158	75	135	17.9 a	289	1,125
	FP	240	52	90	17.1 a	290	1,060
Xining, Qinghai	OPT	158	75	135	30.9 a	289	2,152
	FP	240	52	90	27.5 b	290	1,883
Huaxian, Shaanxi	OPT	181	322	225	47.9 a	596	3,189
	FP	194	504	225	45.8 b	766	2,855
Mizhi, Shaanxi	OPT	307	322	225	26.5 a	686	1,410
	FP	358	0	0	22.5 b	254	1,523
Zhijin, Guizhou	OPT	105	30	66.5	14.5 a	155	993
	FP	75	22.5	0	10.2 b	73	735

† Means in the same location followed by the same letter are not significantly different at $p<0.05$.
‡ The total cost (USD) of N, P, and K fertilizer: N = \$0.71/kg, P_2O_5 = \$0.88/kg, K_2O = \$0.82/kg. (1 USD = 6.36 RMB)
§ GRF is the gross return to fertilizers and manures (when applied). Potato tuber price = \$0.079/kg.
¶ Livestock manure applied at 7,500 kg/ha; \$31.45/t
# Livestock manure applied at 22,500 kg/ha; \$31.45/t

to irrigated potato systems, where N release can be regulated by soil moisture content. Experiments conducted in irrigated potato in Inner Mongolia from 2009 to 2011 indicate that, at the same N rate, control-release urea (CRU) resulted in better yield and higher N use efficiency than regular urea (RU). At 75% of the recommended N rate, CRU produced a similar yield and higher N use efficiency compared with RU at the recommended rate (**Table 2**).

While the source of P commonly used in potato varies (e.g. DAP, MAP, SSP, TSP, and calcium-magnesium phosphate) based on regional preference; KCl is the primary K source compared to other sources like K_2SO_4 and KNO_3. High soil K supply is required to maintain both tuber yield and quality, and these in turn can be affected by K source. Either KCl or K_2SO_4 are the preferred sources based on yield data (Qin et al., 2008; Kumar et al., 2007). Evidence suggests tuber starch and vitamin C content are increased, and the content of reduced sugar in tubers decreased, when potato is supplied with KCl instead of K_2SO_4 (Qin et al., 2008).

Organic nutrient sources such as animal manures and/or organic compost are effective nutrient sources in potato production. However, the combined use of manure with balanced application of fertilizer typically results in better yield (and economic returns) over those obtained with fertilizer or manure alone (Gallandt et al., 1998; Parmar et al., 2007).

The Right Rate

A number of approaches have been developed to help determine proper fertilizer application rates in China's agriculture. Generally, a fertilizer recommendation based on soil testing and a target yield is commonly used for potato. The ASI systematic approach for soil testing and nutrient recommendation (Hunter, 1980; Portch and Hunter, 2002) was found to be an effective nutrient management tool and is widely used in China (Jin et al., 2006). Compared to farmer's practice (FP), more balanced, "optimum" treatments (OPT) recommended by the ASI procedure have increased tuber yields by an average of 3 t/ha, and farmer's income by nearly USD 200/ha (**Table 3**).

Applied P generally has maximum solubility within a narrow range in which P is not tied up in low solubility complexes with Fe and Al or Ca (Davenport et al., 2005). A common practice within China is to add P fertilizers in excess of plant removal (average requirement of 1.3 kg P_2O_5/t; see **Table 1**) to overcome the effects of soil reactions that reduce P solubility (Davenport et al., 2005).

Few soils can produce high potato yields for many seasons without replenishing the K removed by harvested tubers. IPNI field data have found K responses as high as 22.2 t/ha in Qinghai with the application of 97 kg K_2O/ha; and 16.7 t/ha in Gansu when 150 kg K_2O/ha was applied.

Irrigated potato requires more nutrients and higher ap-

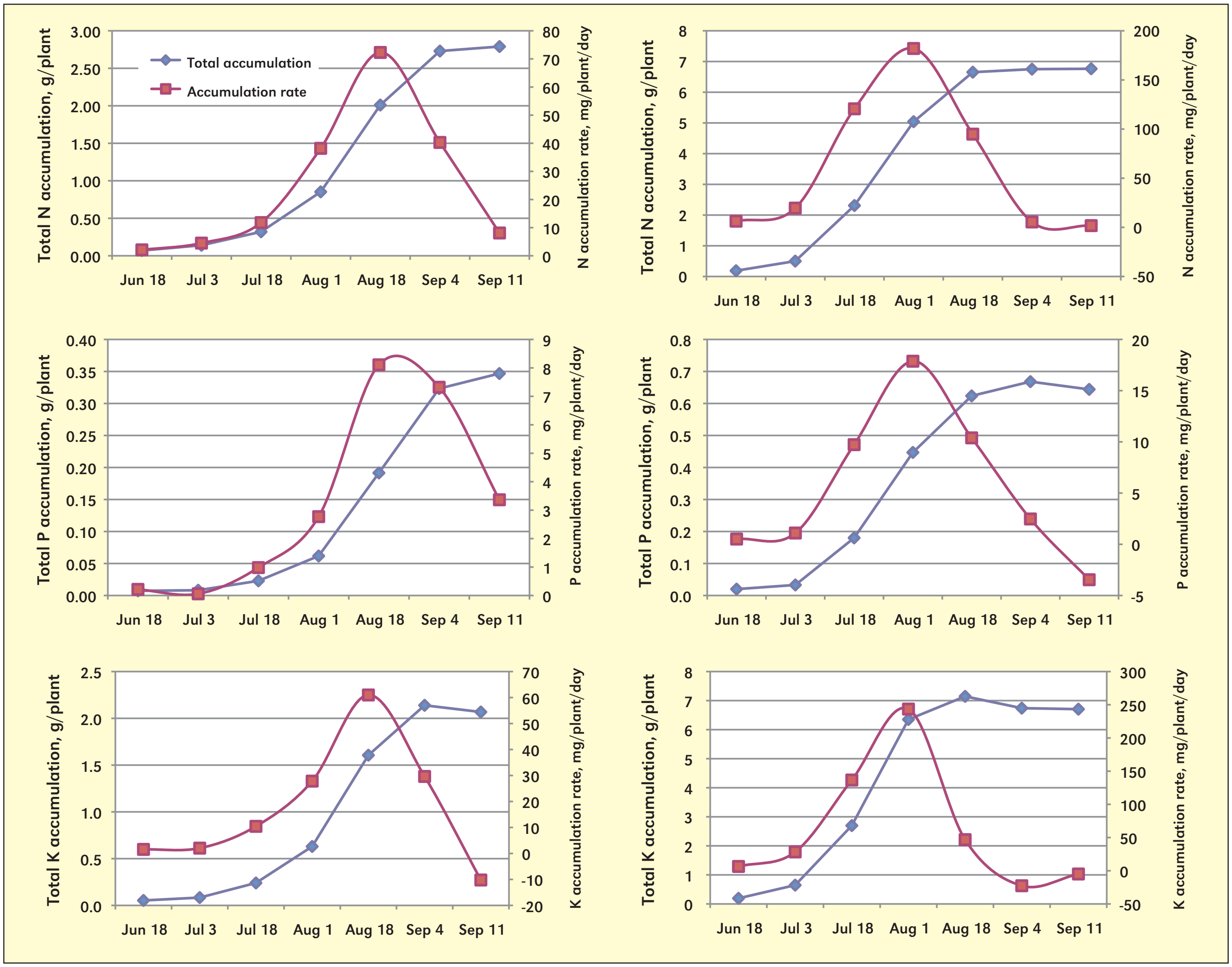

Figure 1. Characteristics of total and daily rates of N, P, and K accumulation by rainfed (left) and irrigated (right) potato (cv. Zihuabai) in Inner Mongolia.

plication rates than rainfed sites due to the much higher yield potential. Drip fertigation can reduce recommendations for both N and K rate compared to furrow irrigation while still maintaining higher total tuber yield (Sasani et al., 2006).

After N and K, Ca and Mg are removed in the next largest quantities by potato (Westermann, 2005). The acidic red soils (Ferralsols) in south China are especially Ca- and Mg-deficient and require significant amounts (90 kg Ca/ha and 60 kg Mg/ha) supplied as lime gypsum, $MgSO_4$, $MgCl_2$, and dolomite.

The Right Time

Knowledge of total season demand and the daily nutrient uptake can provide the guidance required for determining the proper timing for nutrient application. **Figure 1** is an example of nutrient uptake and accumulation by rainfed and irrigated potato in Inner Mongolia. Nutrient is accumulated rapidly during tuber bulking stage. The highest daily nutrient uptake by irrigated potato appears about 2 weeks earlier than rainfed potato, suggesting nutrients need to be applied earlier for irrigated potato to match demand.

Excessive N fertilizer applied at or before tuber setting can extend the vegetative growth period and delay tuber development, resulting in a lower tuber yield. However, too much N applied later in the season can delay maturity of the tubers, reducing yield and adversely affecting tuber quality. Split application of N can meet the demand of plant uptake, improve nutrient use efficiency, and provide increased flexibility in fertilizer N management, allowing the grower to modify N management based on crop growth stage and climate conditions. In some areas with irrigation or high rainfall, N can be applied in three or four splits to improve yield and nutrient use efficiency. In irrigated production on sandy soils, split N application is very effective in reducing environmental N losses (Errebhi et al., 1998). However, there is little or no benefit to split N application in situations where the risk of nitrate leaching is low.

All P and K fertilizers are generally applied pre-plant and mixed with soil before planting. Micronutrients such as Zn, Mn, and Fe applied pre-plant may oxidize or precipitate to unavailable forms before plant uptake, particularly on calcareous soils with high pH. Elemental S should be applied in advance of planting, allowing S oxidization to plant available sulfate, especially in cold areas and on soils with low S oxidation capability.

The Right Place

Nutrients can be applied in various ways to meet the requirements for potato production. Most nutrients, including N, can be applied pre-plant if tilled into the rooting zone before planting. Both Mn and Fe applied pre-plant may oxidize to unavailable forms before plant uptake, particularly on the high pH calcareous soils. Nutrient source also influences application method and rate. Fertilizer applications after planting are usually done before row closure. When topdressing fertilizer materials are broadcast on the soil surface and should be followed by tillage operation such as ridging. Side-dressed materials are usually physically injected into the soil a few centimeters away from the potato seed.

Fertigation can be an alternative practice for nutrient application, particularly if the nutrient is mobile in the soil, such as nitrate. Fertigation application of nitrate can be more efficient than a pre-plant application when the nutrient is not leached out of the plant's root zone during the process (Westermann et al. 1988). When nutrients are easily fixed by the soil (e.g. P in calcareous soil or acidic, red soil) they should not be applied by fertigation. In Northern China, where a single crop of potato is grown each year, consolidated farms with up to 100 ha of potato fields are becoming more common. Potato is irrigated by sprinkler irrigation systems, which can provide flexibility and efficient water application. Nitrogen and K fertilizer can both be applied through sprinkler irrigation.

Fertilizer banding can also improve efficiency of fertilizer N and P use. Banding fertilizer in ridges would also be expected to reduce the risk of nitrate leaching because of greater water infiltration in the furrow compared with the ridges (Zebarth and Rosen, 2007). Because potato has a low P use efficiency and limited ability to take up P at low soil P levels (Dechassa et al., 2003), P should be band applied to increase the P concentration in the root zone.

Summary

Results from this research indicate that there is considerable opportunity to modify fertilizer rates for potato production in China. While degraded soils can influence the nutrient rates applied, the negative impact from the overuse of nutrients must be addressed. Fertilizer rates not only depend on potato requirements, but on fertilizer source, water regime, and soil conditions. The best nutrient management practice for potato is to apply nutrients using right source, right rate, right time, and right place (4R) strategies for high tuber yields and nutrient use efficiency. The determination of these four "rights" is a location (or site-specific) process. BC

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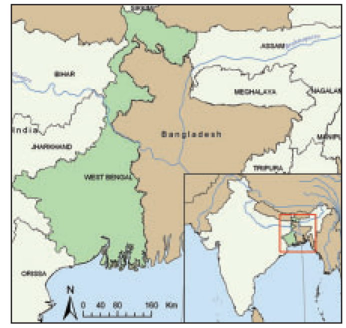
Increasing Use Efficiency of Nitrogenous Fertilizers in Fish Ponds

By Amrita Thakur, Abira Banerjee, and G.N. Chattopadhyay



High amounts of N fertilizers are usually recommended in fish ponds to encourage the growth of primary fish food organisms, and thereby, the growth of fish. However, use efficiency of these fertilizers tends to be low under a submerged environment. Adoption of some simple management practices can improve the efficiency of N fertilizers in fish culture operations.

The major objective of fertilizing fish ponds is to improve the nutrient status of the pond soil-water environment for enhancing the growth and abundance of fish food organisms (Mandal and Chattopadhyay, 1992). Among different pond fertilizing nutrients, high rates of N fertilizers are usually recommended, ranging from 200 to 400 kg/ha (Boyd et al., 2002). However, only a small portion of this added N gets transmitted to fish, while the rest is lost from the pond environment through various processes like volatilization, leaching, denitrification, etc. (Bouldin et al, 1974; Chattopadhyay and De, 1991). These processes result in significant loss of added N from fish pond systems causing substantial reduction in fertilizer N use efficiency (NUE). Major pathways for N loss from fish pond environments are shown in **Figure 1**. Schroeder (1987) found this efficiency to be as low as 18% of the total N added to the pond as manure and fertilizer. On the other hand, Gross et al. (2000), while working on channel cat fish ponds, observed about 31.5% of the added N to be ultimately transmitted to fish flesh. Their study also showed that the loss of N from the fish pond through denitrification and leaching was about 40.5%, while that from volatilization was around 12.5%. Such large-scale losses not only add to the cost of an aquaculture operation, but are also likely to affect the quality of ground water through leaching of NO_3^--N.

Mandal and Chattopadhyay (1992) suggested that maintaining higher amounts of NH_4^+-N than NO_3^--N in the pond environment may increase NUE. Since NH_4^+ ions can be adsorbed by bottom soil colloids in an easily exchangeable phase, N loss will be less and, as a result, N availability to primary fish food organisms will be improved. However, NH_4^+ ions are also subject to loss through volatilization under highly alkaline conditions—a typical situation encountered in productive fish ponds, especially during high sunshine periods. But the magnitude of this loss is quite less in a fish-pond system when compared with the loss from upland soils (Chattopadhyay, 2004). This paper discusses possibilities of using different N management practices to prevent the loss of N mainly in NO_3^- form and, thus, increase NUE in pond fish culture system.

In rice soils, use of different nitrification inhibitors is gaining popularity for increasing NUE. In view of the similarity between fish ponds and submerged rice soils (Hickling, 1971), Thakur et al. (2004) carried out a mesocosm study to assess the effects of three nitrification inhibitors, viz., neem (*Azadirachta indica*) extract, karanj (*Pongamia glabra*) and sodium azide (NaN_3), on the primary productivity of water under simulated fish pond conditions. All three nitrification inhibitors were used at 1 % w/w with urea added to the submerged soil-water system at 100 kg N/ha rate and incubated under illuminated conditions. The study revealed that the use of nitrification

Common abbreviations and notes: Mesocosm = simulated fish pond environment in large aquariums (term modified from "microcosm" that describes simulated fish pond environment in small glass containers); N = nitrogen; NH_4^+ = ammonium ions; NO_3^- = nitrate ions; OM = organic matter; C = carbon; h = hour.

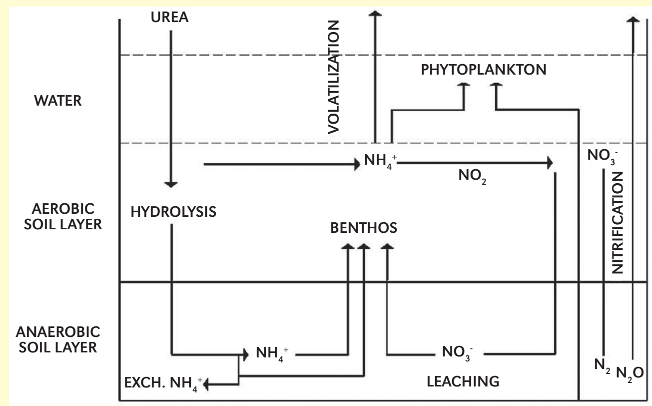


Figure 1. Major pathways for loss of nitrogen from fish pond environment.

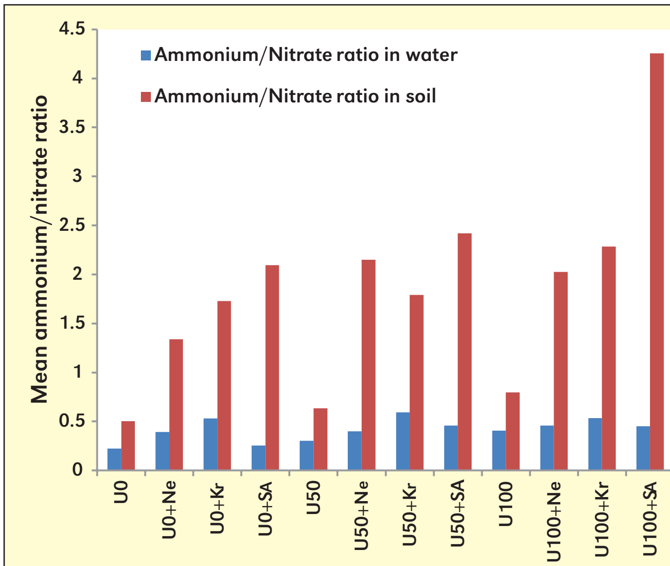


Figure 2. Mean ammonium/nitrate ratio in soil and water under different treatments with nitrification inhibitors. U_0 = no fertilization, U_{50} = 50 mg N (supplied as urea)/kg soil, U_{100} =100 mg N (supplied as urea)/kg soil, Ne = neem (Azadirachta indica) extract, Kr = karanj (Pongamia glabra) extract, SA = sodium azide (NaN_3).

Table 1. Effect of nitrification inhibitors on water soluble nitrogen (NH_4^++ NO_3^- mg/l).

Treatment	15	30	45	60	75	Average
	Days of Incubation					
U_0	3.47	7.77	5.20	23.8	18.2	11.7 g
U_0+Ne	6.77	8.40	9.52	28.2	24.9	15.6 ef
U_0+Kr	4.81	8.96	6.26	27.7	26.6	14.9 f
U_0+SA	5.25	9.03	7.98	26.7	23.4	14.5 f
U_{50}	4.14	9.33	8.17	25.3	21.7	13.7 f
U_{50}+Ne	8.51	10.1	11.6	38.9	32.9	20.4 bc
U_{50}+Kr	6.60	10.1	11.0	45.1	30.6	20.7 b
U_{50}+SA	7.05	13.1	8.95	34.0	30.0	18.6 cd
U_{100}	6.02	10.3	10.5	27.8	30.2	17.0 de
U_{100}+Ne	10.2	11.0	14.5	43.7	38.6	23.6 a
U_{100}+Kr	7.95	12.2	12.4	51.6	33.6	23.3 a
U_{100}+SA	8.00	14.0	13.6	37.1	32.3	21.0 b
LSD (p=0.05)	1.64	2.01	2.76	13.5	5.96	

Adapted from Thakur et al. (2004). U_0 = no fertilization, U_{50} = 50 mg N (supplied as urea)/kg soil, U_{100} = 100 mg N (supplied as urea)/kg soil, Ne= neem (Azadirachta indica) extract, Kr = karanj (Pongamia glabra) extract, SA = sodium azide (NaN_3). Averages followed by the same letter in the column are not statistically different.

Table 2. Effect of organic matter on readily available nitrogen and gross primary productivity under simulated fish pond condition.

Treatment	Mean water soluble N (NH_4^++ NO_3^-), mg/l	Mean mineralized N (NH_4^++ NO_3^-) in soil, mg/kg	Mean gross primary productivity of water, mg C/m^3/h
N_0SA_0	10.1	101	124
N_0 SA_{100}	11.0	114	154
N_0 SA_{200}	12.4	124	176
N_{50} SA_0	16.0	139	158
N_{50} SA_{100}	16.4	150	207
N_{50} SA_{200}	17.1	164	250
N_{100} SA_0	15.4	171	182
N_{100} SA_{100}	16.8	173	264
N_{100} SA_{200}	17.6	176	301
LSD (p=0.05)	1.6	6.14	46.6
SEM	0.52	2.05	15.6

N_0, N_{50}, N_{100} = N at 0, 50, and 100 mg/kg soil, respectively; SA_0, SA_{100}, and SA_{200} = 0, 100, and 200 mg organic material (starch)/g urea, respectively.

inhibitors resulted in a substantial increase in NH_4^+/ NO_3^- ratios in soil and water, as compared to the treatment without any nitrification inhibitor (**Figure 2**). Nitrification inhibitors helped maintain larger amounts of N in readily available forms (NH_4^+ + NO_3^-) in soil and water (**Table 1**).

High amounts of organic manures are often used in the fish pond systems in Asian countries (Prowse, 1966). Generally, manures and mineral fertilizers are recommended to be used separately keeping an interval of 15 days in a month (Anon, 1985). During the period of decomposition of organic manures, the dissolved oxygen in water is used by decomposer microbes. As a result, a semi-aerobic or even anaerobic condition may develop near these decomposing organic materials. The magnitude of such development will depend on the decomposability and quantity of the organic load. It was thought that this behaviour of organic manures may be effectively utilized for improving the use efficiency of urea under fish pond conditions. Combined use of OM and urea is likely to develop a semi-aerobic environment around the added fertilizer, thus restricting the rapid transformation of the nutrient into NO_3^- form in the absence of adequate availability of oxygen.

Taking this hypothesis into consideration, another mesocosm study was carried out to assess the effect of using urea along with OM on NUE (Thakur et al., 2004). In this study, starch was used as OM and was mixed with urea at 0, 1%, and 2% (w/w). Urea, mixed with and without starch, was added to the soil-water system at 0 and 50 kg N/kg soil. Use of the starch treated urea maintained higher levels of NH_4^+-N and NO_3^--N in both soil and water phases and also helped to increase the gross primary production of water from 45 to 66% over the no OM treatment (**Table 2**). In fish culture, fertilizers are generally applied once a month. However, in view of the large-scale loss of N fertilizers from the fish ponds, it was hypothesized that split application of N fertilizers may provide a steady source of N to the primary fish food organisms. This is also expected to prevent high accumulation of N in the soil-water system at any point of time, thus helping to reduce the loss of unutilized N from the culture system. To assess the efficiency of this concept, use of 100 kg N/ha/yr was split into once-a-month, once-a-fortnight (14 days), and once-a-week treatments, keeping the total N application rate same under each of these three treatments. The study revealed that more frequent application of urea resulted in higher production of primary fish food organisms as compared to once-a-month urea application (**Figure 3**).

Since these container studies appeared to be quite effective in improving N availability to primary fish food organisms, an on-farm trial was conducted with the objective of assessing the efficiency of combined use of these N management practices under actual field conditions. For this purpose, two fish ponds of similar nature were selected at Goalpara village of Birbhum district of West Bengal, India. Both ponds were treated with similar nutrient rates, (i.e. N at 100 kg/ha/yr, P_2O_5 at 100 kg/ha/yr, and K_2O at 20 kg/ha/yr.) In one pond, the fertilizers were used at once-a-month intervals as per the conventional norm of fish pond fertilization practiced in India. In the second pond, N was mixed with neem extract at 1% w/w and cow dung slurry at 1:10 urea: slurry ratio and was applied in once-a-fortnight intervals. Phosphorus and K were applied once-a-month just like in the other pond. All other fish culture operations were carried out in similar manner in both the ponds. The beneficial effects of N management

Table 3. Effect of N management practice on some chemical and biological parameters of fish pond soil and water.

Parameters (Mean values)	Conventional fertilization	Developed fertilization
$NH_4^+ + NO_3^-$ in soil, mg/kg	156	142
$NH_4^+ + NO_3^-$ in water, mg/kg	16.9	17.5
Gross primary productivity, mg $C/m^3/h$	543	733
Net primary productivity, mg $C/m^3/h$	397	515

practices were reflected in primary productivity of the pond water. Improved N management practices increased gross and net production of primary fish pond organisms by 35 and 30%, respectively, over conventional practices (**Table 3**). However, the mean value of mineralized N in the soil phase was found to be marginally lower in the case of developed pond fertilization. This may be due to the larger uptake of N by primary fish food organisms and also slower release of N into mineralized forms.

It is well established that in any natural pond system, growth and yield of fish are directly dependant on primary productivity levels of the pond (Lavrentyeva and Lavrentyev, 1996). Olah et al. (1986), while working on the productivity of fish ponds under different management practices in India, stated that, on an average, about 2% of the C synthesized through gross primary productivity of water is converted into fish flesh. Using this value, Mandal and Chattopadhyay (1992) suggested that for achieving a fish production of 1,000 kg/ha/yr fish pond water should have the capacity to assimilate 13.7 g C/m^3/day through photosynthesis under Indian conditions. The improved N management practice in our on-farm trial resulted in additional primary production of 190 mg $C/m^3/h$ or 2.30 g C m^3/day over the conventional nutrient application system. Using the value from Olah et al. (1986), this additional primary production may be considered equivalent to about 168 kg of fish production per hectare pond area. At an estimated fish price of INR 100/kg (USD 1.93), the increased primary production is likely to fetch an additional gross income of INR 16,800 (USD 325).

A view of farmers harvesting fish from a fish pond in West Bengal.

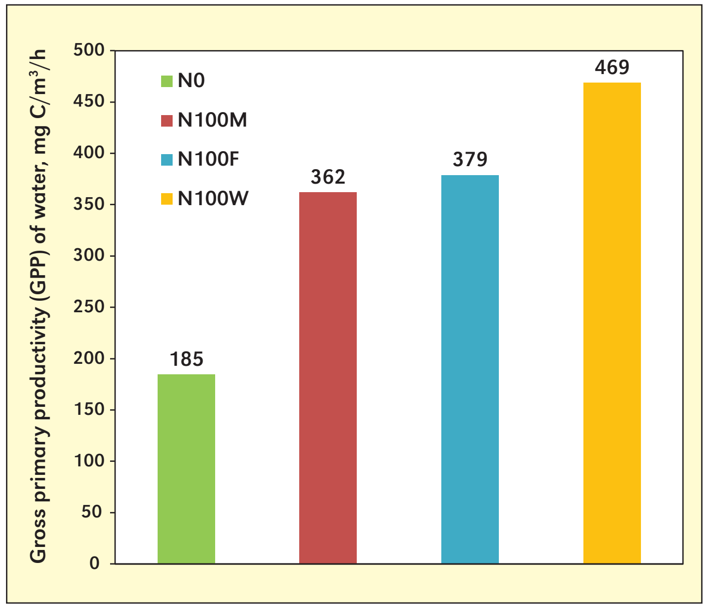


Figure 3. Gross primary productivity (GPP) of water under varying intervals of fertilizer application N0 and N100 = 0 and 100 mg/kg/yr of fertilizer N, respectively; M, F and W = once-a-month, once-a-fortnight, and once-a-week N fertilizer application, respectively.

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Sulfur Effects on Cotton Yield Components

By X.H. Yin, C.O. Gwathmey, and C.L. Main

Little is known about the effects of S deficiency on cotton yield components. In container-grown cotton, S deficiency reduced seedcotton weight and the number of bolls per plant, leaving a greater proportion of bolls at first-position fruiting sites.

Soil available S is generally low in the Cotton Belt region due to the hot and humid climate and high likelihood of sulfate leaching. Increased use of S-free fertilizers, greater S removal from soil by crops with higher yields, less S deposition to soil from the atmosphere, and decreased use of S-containing pesticides have contributed to more S deficiencies in crops during recent years. Little is known about the effects of S deficiency on cotton yield components, and there are few guidelines available about S fertilization to optimize cotton production in Tennessee and other states in the Cotton Belt region.

Container-grown cotton plants receiving low and high rates of S fertilization. Plants under low S treatment are in the foreground; plants under high S treatment are in the background.

A container-grown cotton study was conducted at Jackson, TN during 2008 to 2010 to examine the effects of S deficiency on cotton yield components. Cotton cultivar ‘PHY375WRF’ was planted each year in 15 gallon pots placed outdoors. The rooting medium was a blend of Fafard 2-B and 3-B mixes in 2008 and Fafard 2-B mix in 2009 and 2010 (BWI Companies, Memphis, Tennessee).

Two S treatments, consisting of low and high S concentrations in solution, were applied to the pots by drip irrigation each year. The low S concentration treatment supplied 0 ppm S in 2008 and 1 ppm S in 2009 and 2010 as potassium sulfate. The high S concentration treatment supplied 20 ppm S in the irrigation solution each year. Six replications of the S treatments were applied on a 3-day interval from pre-square to early bloom growth stage each season. The differential nutrition phase of the experiment was followed by a recovery phase in which the high-S treatment was applied to all plants. Adequate amounts of other essential nutrients were supplied to all plants throughout the season. Leaf blade samples were taken from the highest fully expanded main-stem leaves, usually three or four nodes from the terminal at early-bloom and late bloom.

Sulfur Deficiency Symptoms

Classical S deficiency symptoms began to appear in low S concentration-treated plants at about 10 days after treatment began each year (see Photo). Symptoms became more severe until the recovery phase of the trial started, during which the S-deficient plants produced new vegetative growth in response to the restoration of S nutrition. Plants under the high S concentration treatment grew normally.

Leaf Nutrient Concentrations

The low S treatment significantly reduced S concentrations in leaves at early bloom compared to the high S treatment during the differential nutrition phase of the study in all 3 years (**Table 1**). However, as S nutrition was restored during the recovery phase, leaf S concentrations were not significantly different between the two treatments at late bloom in any year. This result was expected because the low S treated plants had been fed with adequate S for several weeks before the later sampling date.

Table 1. Sulfur effects on leaf S concentrations at early and late bloom stages.

Growth stage	Year	Low S	High S
		---------- %	----------
Early bloom	2008	0.08b	0.17a
	2009	0.08b	0.23a
	2010	0.14b	0.16a
	Average	0.10b	0.19a
Late bloom	2008	0.41a	0.34a
	2009	0.27a	0.30a
	2010	0.27a	0.26a
	Average	0.32a	0.30a

Values in each row followed by a different letter are statistically different at p = 0.05.

The low S treatment had higher N, P, K, Ca, and Mg concentrations in leaves than the high S treatment during the differential nutrition phase on the 3-year averages (**Table 2**). One possible explanation for the higher concentrations of these nutrients in leaves with the low S treatment is that the low S-treated plants grew more slowly than those receiving high S, reducing the effect of nutrient dilution due to plant growth.

Common abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; Ca = calcium; Mg = magnesium; S = sulfur; ppm = parts per million.

Table 2. Sulfur effects on leaf N, P, K, Ca, and Mg concentrations at early bloom (3-year averages).

	Concentration in leaf, %				
S treatment	N	P	K	Ca	Mg
Low	4.46a*	0.69a	2.81a	2.01a	0.51a
High	3.46b	0.32b	1.76b	0.88b	0.39b

Values in each column followed by a different letter are statistically different at p = 0.05.

Seedcotton Yields and Yield Components

Seedcotton weight per plant on sympodial branches was significantly reduced under the low S treatment in 2009 and 2010 and on the 3-year averages (**Figure 1**). Seedcotton weight per boll of sympodial branches was also significantly decreased in the low S treatment averaged over the 3 years (**Table 3**).

The low S treatment significantly reduced the total number of harvestable bolls per plant on the 3-year averages (**Table 3**). The low S treatment produced a higher percentage of first-position bolls than the high S treatment averaged over the 3 years. These results suggest that S deficiency affected distal bolls more severely than first-position bolls.

On the 3-year averages, the low S treatment significantly reduced the number of locules per boll (**Table 3**). However, the number of seeds per locule or the first position fuzzy seed index was not affected by S treatment when the 3-year results were combined (**Table 3**). The lack of treatment effects on fuzzy seed index was noteworthy, given the role of S as an amino acid component in cotton seed.

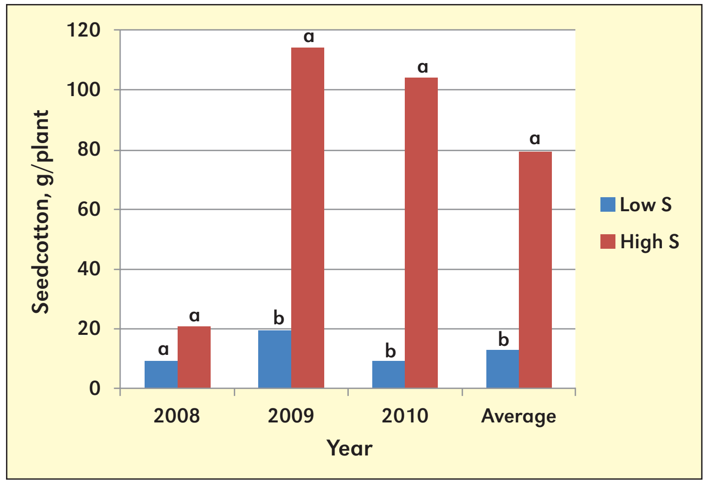

Figure 1. Sulfur effects on seedcotton yield. Values in each year or average followed by a different letter are statistically different at p = 0.05.

Summary

Low S treatment induced visible S deficiency symptoms and reduced leaf S concentrations, but leaf concentrations of other nutrients usually were higher in S-deficient plants. Sulfur deficiency reduced seedcotton weight per boll and per plant, averaged over the 3 years. Sulfur deficient plants usually produced fewer bolls per plant, with a greater proportion of bolls at first-position fruiting sites. Sulfur deficiency also reduced locules per boll on a 3-year average. Results indicate that several cotton yield components may be adversely affected by S deficiency during early growth stages, even if adequate S nutrition is restored later in the season. BC

Table 3. Sulfur effects on yield components of sympodial branch bolls (3-year averages).

Treatment	Seedcotton, g/boll	Bolls/ plant	Bolls at first position, %	Locules/ boll	Seeds/ locule	Seed index, g/100 seeds
Low S	2.6b	4.9b	70.6a	3.4b	4.9a	9.0a
High S	3.7a	19.1a	37.0b	4.0a	4.8a	9.8a

Values in each column followed by a different letter are statistically different at p = 0.05.

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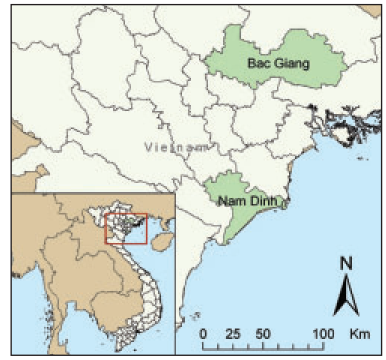
Foliar Potassium Nitrate Application for Paddy Rice



By Tran Thuc Son, Le Xuan Anh, Yoav Ronen, and Harmen Tjalling Holwerda

Trials conducted in Vietnam with spring and summer rice grown on soils low in soil exchangeable K showed positive yield and net income responses from one to three foliar treatments with potassium nitrate. Grain yields and net income were improved when a portion of the basal KCl was replaced with the three foliar KNO_3 sprayings.

The importance of rice in relation to Vietnam's food security, culture, and socio-economic development is evident. Total annual paddy rice production grew from 19.2 million tonnes (M t) in 1990 to 35.8 M t in 2005, and 38 M t in 2008. Thus, Vietnam has moved from being a country with a chronic food deficit to one with enough food for its population, enhanced food security and a food surplus that allows rice exports of 5 to 6 M t per year. Major constraints to improving productivity and economic performance of rice include low soil fertility, pest and disease damage, poor availability and high cost of inputs, as well as low and fluctuating rice prices.

Modern high-yielding rice varieties absorb K in greater quantities than any other essential nutrient. In fields across Asia, total K uptake for a crop yielding 5 t/ha are close to 100 kg K/ha of which more than 80% is in the straw at maturity (Dobermann and Fairhurst, 2000). For yields greater than 8 t/ha, total K uptake may even exceed 200 kg K/ha (Dobermann et al., 1996). Current K fertilizer recommendation and application rates are rarely sufficient to meet these K needs. Therefore, most intensive rice production systems have been running under negative K balances (Dobermann et al., 1998) and the negative effects of this have begun to emerge (Regmi et al., 2002; Bhanderi et al., 2003). The situation is even more aggravated when all the straw is removed from the field as per farmer practice in North Vietnam. In some locations, nutrients removed by crop are partly returned to the soil in the form of FYM. However, the use of FYM or straw may be profitable only when applied as a complement to recommended rates of NPK fertilizer (Dawe et al., 2003).

Foliar applied K can be beneficial when K uptake via the root zone is limited. This condition may be due to low K input via fertilizers, low K soil reserves, K-fixing soils (clay, high OM, peat), cation competition (sodic/saline soils with high Na; excessive NH_4 fertilizers applications; high Fe), course-textured sandy soils, vulnerability to K leaching (monsoons), or drought which limits the transport of K to roots (adapted after Weinbaum et al, 2002).

In 2009, researchers in Vietnam conducted experiments with foliar KNO_3 (13% N and 45% K_2O) sprays in paddy rice in North Vietnam to evaluate its effect on yield and yield components, nutrient uptake, as well as agronomic and economic efficiency. Four field experiments were conducted at two locations including: a degraded soil site at Bac Giang Research Station located in Hiep Hoa District, Bac Giang Province, and an alluvial soil site on the Red River Delta in Xuan Truong District, Nam Dinh Province. Soil properties in the surface soil layer of the degraded soil and alluvial soil as well as details on rice varieties and plant spacing are provided in **Table 1**. The degraded soil is prone to leaching of K, and the alluvial soil is associated with K fixation. Both of these soils displayed very low soil exchangeable K contents, making them potentially very responsive to K addition.

Common abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; Fe = iron; Na = sodium; C = carbon; KCl = potassium chloride; KNO_3 = potassium nitrate; SSP = single superphosphate; NO_3 = nitrate; NH_4 = ammonium; FYM = farmyard manure; OM = organic matter; CEC = cation exchange capacity; VND = Vietnamese dong.

Table 1. Description of the experimental sites, rice varieties, and planting density at Nam Dinh and Bac Giang.

Parameter	Bac Giang	Nam Dinh
Soil type	Degraded, sandy soil	Alluvial, clayey soil
Exc K, cmol/kg (ppm)	0.08 (31)	0.15 (59)
Organic C, g/kg	8.6	13.5
CEC, cmol/kg	4 to 5	15
pH	5.5	5.5 to 6.0
Spring rice	Inbred Khang Dan 18	Hybrid Juu 527 (China)
Summer rice	Inbred Khang Dan 18	TH3-3 (Vietnam)
Plant spacing	20 cm x 10 cm	25 cm x 13 cm

Foliar KNO_3 was provided along with combinations of basally applied urea, SSP, KCl, and 8 t/ha of FYM (spring rice only) (**Table 2**). Foliar applications occurred at one or more different growth stages: Active Tillering (AT), Panicle Initiation (PI), and End of Flowering (F), and each application provided 300 liters of a 3% concentration, equal to 9 kg KNO_3/ha, or 4 kg K_2O/ha and 1.1 kg N/ha. Hills from 4 m^2 of area centered in each replicated plot were harvested for grain yield determination with 14% moisture. Yield components were determined from 10 hills collected from the sampling zone surrounding the harvest area, as was the procedure for determining dry biomass at the AT, PI, and F stages.

The response to direct FYM application can be quantified in spring rice and was significant ($p = 0.05$) at the degraded soil site at Bac Giang, but not at the alluvial soil site at Nam Dinh (**Table 3**). In summer rice, check plots showed a significant difference between the basal NP treatment and basal NP plus foliar KNO_3 applied at each of the three growth stages selected. Reliance on basal K alone produced yields that were equal to those resulting from foliar KNO_3 alone at three of the four sites (i.e. excluding the summer rice season at Nam Dinh) where three splits of foliar KNO_3 was superior. Supplementation of the full basal K rate with three foliar KNO_3 applications (T9) produced the highest average yield response across seasons

Table 2. Fertilizer sources, timings, and rates for the two trial sites in Vietnam.

Source	Timing	Unit	Spring Rice: Bac Giang	Spring Rice: Nam Dinh	Summer Rice: Bac Giang	Summer Rice: Nam Dinh
FYM†	Basal	t/ha	8	8	-	-
Urea (46% N)	10-15 DAT	kg N/ha	30	40	20	30
Urea	25 DAT (AT)	kg N/ha	30	40	30	40
Urea	50-55 DAT (PI)	kg N/ha	30	40	30	30
Total N		kg N/ha	90	120	80	100
SSP (16% P_2O_5)	Basal	kg P_2O_5/ha	60	70	45	60
KCl (60% K_2O)	Basal	kg K_2O/ha	70	90	70	90

†FYM source at BacGiang was 0.32% N, 0.41% P_2O_5, and 0.52% K_2O which added 26 kg N/ha, 33 kg P_2O_5/ha, and 42 kg K_2O/ha; at Nam Dinh the FYM source was 0.35% N, 0.43% P_2O_5, and 0.55% K_2O which added 28 kg N/ha, 34 kg P_2O_5/ha, and 44 kg K_2O/ha.
DAT = Days after transplanting, AT = Active Tillering, PI = Panicle Initiation.

Table 3. Treatments, application stages, applied dose rates and yields for the two trial sites in Vietnam.

	Treatment description†	Foliar KNO_3 timing‡: AT	PI	F	Spring 2009: Bac Giang	Spring 2009: Nam Dinh	Summer 2009: Bac Giang	Summer 2009: Nam Dinh
					Yield††, t/ha			
T1a	NP* without FYM	0	0	0	4.74	6.59	3.75	4.62
T1b	NP	0	0	0	5.05	6.80		
T2	NP	+	+	+	5.59	7.80	4.47	5.38
T3	NP + 100% KCl (Basal)	0	0	0	5.53	7.30	4.52	4.95
T4	NP + 100% KCl (Basal)	+	0	0	5.78	7.84	4.90	5.29
T5	NP + 100% KCl (Basal)	0	+	0	5.79	8.02	4.89	5.41
T6	NP + 100% KCl (Basal)	0	0	+	5.83	7.87	4.83	5.36
T7	NP + 100% KCl (Basal)	+	+	0	5.86	8.16	5.13	5.48
T8	NP + 100% KCl (Basal)	0	+	+	5.94	8.18	5.14	5.50
T9	NP + 100% KCl (Basal)	+	+	+	6.16	8.49	5.26	5.67
T10	NP + 75% KCl (Basal)	+	+	+	6.12	8.33	5.13	5.43
T11	NP + 50% KCl (Basal)	+	+	+	6.06	8.15	5.02	5.41
T12	NP + 50% KCl (Basal) + 50% KCl (PI)	0	0	0	5.74	7.97	4.78	5.21
	LSD (p = 0.05)				0.14	0.58	0.11	0.34

†In spring rice, all treatments received FYM except T1a. In summer rice, no FYM was applied
‡0 = no foliar K, + = 9 kg KNO_3/ha/application, AT = Active Tillering (20 to 25 DAT), PI = Panicle Initiation (50 to 55 DAT), F = End of Flowering (25 to 28 days before harvest).
††Grain yields are adjusted to 14% moisture.
* Rates for N and P are described in Table 2.

and sites. This treatment produced 11% more spring rice and 16% more summer rice on degraded soil; 16% more spring rice and 15% more summer rice on alluvial soil compared to use of basal KCl alone (T3). Single sprays resulted in a more modest yield response of 7% averaged over sites and seasons, while two sprays generated an average yield response of 11%. Interestingly, significantly higher yields (10% average response) were also obtained with the combination of three foliar KNO_3 sprays and up to 50% less KCl provided through a base dressing (T10 and T11). While in this study no disease ratings were carried out on the rice crops, the authors suggest that foliar KNO_3 applications may have increased the plants' disease and pest tolerance.

The corresponding agronomic efficiencies (AE) for K declined with increased frequency of foliar KNO_3 spray as a result of diminishing gains in yield per unit of K input (data not shown). Thus at the degraded soil site, AE averaged across both seasons varied from 25 kg rice grain/kg KNO_3 with three sprayings (T9) to 27 kg rice grain/kg KNO_3 with two sprayings (T7 and T8) to 35 kg rice grain/kg KNO_3 with a single foliar spray (T4, T5, and T6). On alluvial soil, average AE values were 56 kg, 39 kg, and 35 kg/kg KNO_3 for the single, double, and triple applications of foliar spray. Higher AE values at the alluvial soil site are most likely related to growing hybrid varieties at that location. Foliar spraying tended to increase the number of panicles/m^2, numbers of grain/panicle, 1,000 grain weight, and decreased the ratio of unfilled grain (data not shown). However, the significance of these responses depended on season and location.

As expected, the higher yields with foliar KNO_3 increased uptake of N and K in both grain and straw at harvest (data not shown). For example, on the degraded soil, average uptake in spring rice increased by 3.5 kg N/ha and 10.5 kg K_2O/ha for the single sprays, while uptake in summer rice was increased by 8.2 kg N/ha and 13.9 kg K_2O/ha. Nutrient removal per t of grain ranged between 15 to 17.2 kg N and 22 to 24 kg K_2O for the inbred variety at Bac Giang and 14.6 to 15.1 kg N and 18.1 to 19.3 kg K_2O for the Juu 527 hybrid (spring) and 16.2 to 17.2 kg N and 23.5 to 24.1 kg K_2O for TH3-3 hybrid (summer) at Nam Dinh.

Economic analysis found a steady increase in net income under single, double, and triple sprayings at both the degraded and alluvial sites (**Table 4**). In addition, net income was maintained when basal KCl was decreased by up to 50% in combination with three foliar KNO_3 spray applications, as well as for the treatment that completely substituted basal KCl with three foliar applications of KNO_3 (T2).

Summary

On these severely K deficient soils, foliar application of KNO_3 provided an increase in paddy rice grain yields and net incomes over basal KCl application across two seasons and sites. The best response was achieved when the maximum basal rate of KCl was applied along with three foliar KNO_3 applications. Reducing the basal dressing of KCl by 25% or 50%, while compensating for this reduction with three foliar KNO_3 sprayings, also achieved higher yields and net incomes than those achieved with strictly basal KCl.

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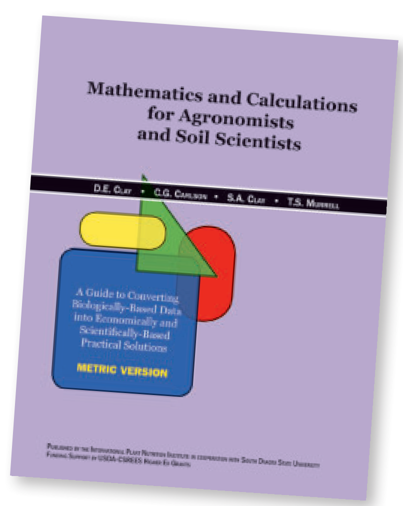
Table 4. Economics of foliar KNO_3 application on rice (average of two seasons) at Bac Giang and Nam Dinh.

Treatment	Gross Income†	Total Fertilizer Cost	Total Fertilizer Cost over T3	Net Income over fertilizer cost	Net over T3
			USD/ha		
			Bac Giang (degraded, sandy soil)		
T2	1,397	248	-35	1,149	36
T3	1,396	283	0	1,113	-
T4	1,483	306	23	1,177	65
T5	1,483	306	23	1,177	65
T6	1,481	306	23	1,175	62
T7	1,526	329	46	1,198	85
T8	1,539	329	46	1,210	97
T9	1,586	352	68	1,235	122
T10	1,563	327	44	1,235	122
T11	1,539	303	20	1,236	123
T12	1,461	289	6	1,172	60
			Nam Dinh (Alluvial soil)		
T2	1,648	285	-62	1,363	178
T3	1,531	347	0	1,184	-
T4	1,641	370	23	1,271	87
T5	1,679	370	23	1,309	125
T6	1,654	370	23	1,284	100
T7	1,705	393	46	1,312	128
T8	1,710	393	46	1,317	133
T9	1,770	415	68	1,355	170
T10	1,720	384	37	1,336	152
T11	1,695	353	6	1,342	158
T12	1,648	353	6	1,295	111

†1 kg of rice grain = 5,000 VND (Kang Dan variety in Bac Giang), 1 kg of rice grain = 4,500 VND (hybrid rice in Nam Dinh); 1 kg KNO_3 = 23,400 VND, 1 kg urea = 7,000 VND, 1 kg SSP = 3,500 VND, 1 kg KCl = 15,000 VND, 1 USD = 18,000 VND (November 2009).

Mathematics and Calculations for Agronomists and Soil Scientists ...Available Soon in Metric!



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The Agronomy Age

As a new year begins, I often find myself taking inventory of the "big ideas" of the last year. This year has been no different. One prominent idea exclaims that "This is the Agronomy Age!" because so many of the major challenges the world faces today and in the foreseeable future can only be met with the involvement of agronomic science and the technology and practices that stem from it. The plant nutrition industry plays a major role it that process. Some might view the Agronomy Age as an age of the past because agronomy is an old discipline. In fact, over the last couple decades in North America, in the interest of appearing more exciting and cutting edge to students and granting agencies, many of our universities eliminated "agronomy" from their department names.

In reality, the discipline of agronomy remains only partially developed today, but the tools now exist to rapidly make progress in more systematic integration and application of the pieces of the science. This publication features many of those tools and their development and promotion are major roles of IPNI programs.

The process of 4R Nutrient Stewardship has become a major IPNI program emphasis, a process that includes nutrient performance assessment. Science tells us that applied plant nutrients can meet stakeholder performance expectations only when they are used in systems where all the agronomic pieces have been properly assembled. The success of IPNI programs and the fertilizer industry is dependent on this age indeed being the Agronomy Age.

The opportunities in agronomy today are immense, but progress is often threatened by lack of a critical mass of financial and human resources. Much is to be gained through forging partnerships across disciplines, political boundaries, public and private sectors, and generations of scientists and practitioners.

So as we close one year and launch another, I am grateful to be partnered with a team of highly talented and dedicated staff focused on a critical mandate and for the members and other supporters that enable us to fully participate in this Agronomy Age.

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