BETTER CROPS
SOUTH ASIA (FORMERLY BETTER CROPS–INDIA)

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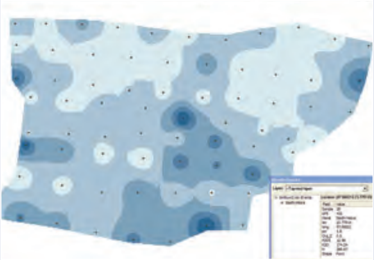
In This Issue...

Fertilising for Sustainable Onion Production Systems

Nutrient Management in the Indo-Gangetic Plains



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BETTER CROPS–SOUTH ASIA

Volume 4, Number 1, December 2010

Our cover: In this scene in a village in the Comilla district of Bangladesh, the viewer can see crops of maize, colocasia, vegetables, and rice seedbeds.

Photo by Dr. Kaushik Majumdar

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Introduction to BETTER CROPS–SOUTH ASIA 2010

Welcome...

You are reading the first edition of this publication under the title of *BETTER CROPS–SOUTH ASIA*, published by the International Plant Nutrition Institute (IPNI). In 2007, 2008, and 2009, this publication was released as *BETTER CROPS–INDIA*. During 2010, the name of our former IPNI India Programme was changed and is now the IPNI South Asia Programme. This reflects the increasing efforts of our very capable staff in the region: Dr. Kaushik Majumdar, Dr. Harmandeep Singh, and Dr. T. Satyanarayana.

This publication follows a format similar to our quarterly publication known as *Better Crops with Plant Food*. However, *BETTER CROPS–SOUTH ASIA* features research articles and information pertinent to this specific region. We at IPNI wish to congratulate and thank the many cooperators, researchers, farmers, industry representatives, and others who are working in a positive mode for South Asia.

Dr. Terry L. Roberts, President, IPNI

2010 Scholar Award Recipients Announced by IPNI

The 2010 winners of the Scholar Award sponsored by the International Plant Nutrition Institute (IPNI) have been selected. The awards of USD 2,000 (two thousand dollars) are available to graduate students in sciences relevant to plant nutrition and management of crop nutrients.

"We had a higher number of applicants for the Scholar Awards this year, and from a wider array of universities and fields of study," said Dr. Terry L. Roberts, IPNI President. "And the qualifications of these students are impressive. The academic institutions these young people represent and their advisers and professors can be proud of their accomplishments. The selection committee adheres to rigorous guidelines in considering important aspects of each applicant's academic achievements."

In total, 16 (sixteen) graduate students were named to receive the IPNI Scholar Award in 2010, with the most widespread geographic distribution ever for the awards. The winners from the South Asia Region are:

Tanumoy Bera, Indian Agricultural Research Institute, New Delhi, India;

Neenu.S, Kerala Agricultural University, Thiruvananthapuram, Kerala, India; and

Hafeez ur Rehman, University of Agriculture, Faisalabad, Pakistan.

Funding for the Scholar Award program is provided through support of IPNI member companies, primary producers of nitrogen, phosphate, potash, and other fertilisers. Graduate students attending a degree-granting institution located in any country with an IPNI program region are eligible. Following is a brief summary for each of the winners from South Asia.


Tanumoy Bera

Mr. Tanumoy Bera is working toward his Doctorate degree in Soil Science at the Indian Agricultural Research Institute. His dissertation title is "Preparation, Characterisation, and Evaluation of Biochar for Enhancing Nutrient Use Efficiency by Rice and Maize." His research focuses on how to enhance nutrient use efficiency by applying biochar (a pyrolysis product of biomass). The study includes characterising biochar from various plant-based residues produced by pyrolysis at different temperatures, optimising rates of application, and assessing impact of biochar on soil properties after crop harvest. For the future, Mr. Bera hopes to continue research to solve practical problems faced by farmers.


Neenu.S

Ms. Neenu.S is completing requirements for her Ph.D. degree in Soil Science and Agricultural Chemistry at Kerala Agricultural University in India. Her dissertation title is "Site-Specific Nutrient Management for Bitter Gourd (*Momordica charantia* L.)." Intensive cultivation in Kerala, in addition to the tropical monsoon climate and undulating topography, have led to severe soil nutrient depletion. Field-specific, integrated crop management strategies are needed for optimum profitability. For the future, Ms. Neenu.S hopes to do research in the field of soil fertility to improve crop production, reduce poverty, and reduce potential harm to the environment resulting from unscientific use of fertilisers.


Hafeez ur Rehman

Mr. Hafeez ur Rehman is completing requirements for his Ph.D. program in Agronomy at University of Agriculture, Faisalabad, Pakistan. His dissertation title is "Nitrogen and Zinc Dynamics under Different Rice Production Systems." Mr. Rehman's research project involved splitting of N and zinc (Zn) at different stages and forms under varying water regimes and their availability, uptake, and partitioning in aerobic and transplanted basmati rice. He hopes to continue research on plant nutrition, particularly characterisation of processes for enhanced Zn uptake and its further loading into rice grains to feed the malnourished people of the world. His work can also help farmers boost rice yields by improved water and nutrient management.

The IPNI Scholar Award recipients are selected by regional committees of IPNI scientific staff. The awards are presented directly to the students at their universities and no specific duties are required of them. Graduate students in the disciplines of soil and plant sciences including agronomy, horticulture, ecology, soil fertility, soil chemistry, crop physiology, and other areas related to plant nutrition are encouraged to apply. More information is available from IPNI staff, from individual universities, or from the IPNI website: >www.ipni.net/awards<. BC-SA

Abbreviations: N = nitrogen.

Nutrient Management Research Priorities in Rice-Maize Systems of South Asia

By Jagadish Timsina, M.L. Jat, and Kaushik Majumdar

Rice-maize (R-M) systems are emerging all around South Asia, but in particular they are developing rapidly in Bangladesh and South and North India. Nutrient demand of R-M systems can be high due to the nutrient extraction of high-yielding crops. Nutrient balance studies for these highly productive and nutrient extractive systems are scarce in South Asia. Developing, refining, and disseminating the integrated plant nutrition system based on site-specific nutrient management (SSNM) principles have been identified as priorities for future research to further increase yield, profitability, and sustainability of R-M systems.

Maize is rapidly emerging as a favorable option for farmers in South Asia as a component crop of rice-based systems. Drivers of such changes are higher productivity and profitability of maize over winter rice or wheat, the two competing cereal crops grown in the winter season in South Asia (Ali et al., 2008, 2009). Far less water is required for maize, as compared to winter rice and wheat. This is viewed as a promising mitigation option of the arsenic (As) problem in the Gangetic regions of West Bengal and Bangladesh where uptake of As with water and its subsequent movement through the food chain (soil-plant-animal continuum) is a great concern. Maize is also considered to be a better alternative to counter abiotic stresses such as terminal heat stress in wheat in eastern India and Bangladesh, and water scarcity in peninsular India. Maize has fewer pest and disease problems than winter rice or wheat. A combination of the above reasons, along with the suitability of maize in the three major cropping seasons of South Asia (Timsina et al., 2010), support diversification from the existing cropping systems to rice-maize systems.

High yielding R-M systems extract large amounts of mineral nutrients from the soil. Proper nutrient management of exhaustive systems like R-M should aim to supply fertilisers adequate for the demand of the component crops, and apply those in ways that minimise loss and maximise the efficiency of use. Of all the nutrients, N, P, and K remain the major ones for increased and sustained productivity. However, high yielding R-M systems can also accelerate the problem of secondary and micronutrient deficiencies, not only because larger amounts are removed, but also because the application of high rates of N, P, and K to achieve yield targets often stimulates the deficiency of secondary and micronutrients (Johnston et al., 2009).

Nitrogen management in the R-M system will require special attention so that potentially large losses can be minimised and efficiency can be maximised. During the growing season of rice, the aim of fertiliser management should be to reduce N loss through denitrification, volatilization, and leaching by either deep placement or split applications to match crop demand and to increase N-use efficiency. The return to aerobic conditions at the end of the rice season sees rapid nitrification of newly formed and existing ammonium. Once the following maize crop is established, split applications of N fertiliser can supplement mineralisation of soil organic matter to meet the N requirement of the crop without undue loss, even under irrigation. Water availability during the dry winter period varies among R-M agro-ecosystems and will determine yield of the maize crop and hence its N requirement. Higher N use efficiency of the system can be achieved if the maize crop leaves little mineral N at the end of the season because high residual soil N may either depress N fixation by a legume crop such as mungbean, or will be lost during puddling for rice (Buresh and de Datta, 1991).

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

Rice and maize are grown on 3.5 million hectares (M ha) in Asia, of which 1.5 M ha are in South Asia.

Phosphorus tends to accumulate in the soil due to fixation by iron (Fe) and aluminum (Al), especially in acidic soils. Over time, large amounts of P can be fixed in that way (Kirk et al., 1990) while slowly contributing to the available P pool of the soil. Phosphorus, however, solubilises immediately after flooding, leading to a flush of available P (Kirk et al., 1990) increasing its supply to rice. Subsequent drying, however, reduces its availability to maize for which strong crop responses to P fertiliser are expected (Sah and Mikkelsen, 1989). In systems of low P fertility, the repeated dry-wet transition in the R-M system increases P extraction, further lowering fertility.

The increased concentrations of ferrous iron (Fe^{2+}), manganese (Mn), and ammonium (NH_4^+) in flooded soils during rice cultivation displace K from the exchange complex into the soil solution. This displacement, however, ceases on return to aerobic conditions. Despite often having relatively high total K content, the K nutrition of R-M systems grown on the soils of South Asia is not always assured. This is attributed to many heavy-textured alluvial floodplain Terai soils of Nepal and northern and eastern India, and the soils of Bangladesh that contain K-fixing minerals (Dobermann et al. 1996, 1998). It may seem appropriate to make differential applications of K to component crops in R-M systems on non-K fixing soils with the aim of preventing loss by leaching. Finally, K inputs from irrigation or rainwater need to be considered (Dobermann et al. 1998) along with K inputs from sediments deposited from flood water while formulating a rational K management strategy for R-M systems. Application of a full maintenance rate of K (input=output) may not be profitable for rice and maize under situations where crop response to K is poor. In such scenarios, some K mining may be allowed by applying K below maintenance rate (Buresh et al., 2010) based on better understanding of how much mining can be allowed in a particular soil without compromising fertility levels.

Site-Specific Nutrient Management in R-M Systems

In south Asia, existing fertiliser recommendations for rice and maize often consist of one predetermined rate of nutrients for vast areas of production. However, the growth and needs for supplemental nutrients of any crop can vary greatly among fields, seasons, and years as a result of differences in crop-growing conditions, crop and soil management, and climate. SSNM for rice and maize enables adjustments in nutrient application to accommodate the field-specific needs of the crop for supplemental nutrients.

Emerging evidence from SSNM experiments in South Asia are highlighting the applicability and necessity of SSNM in R-M systems. SSNM experiments on R-M systems located in Hyderabad, India, revealed that highest yields for both rice and maize, and highest system productivity were obtained from the SSNM treatment (Timsina et al., 2010). Omission of N from the optimum treatment reduced yield by about 1 t/ha and 3 t/ha in rice and maize, respectively. Yield loss in rice and maize (0.8 t/ha and 1.5 t/ha, respectively) was similar in P and K omission treatments. This suggests that N is by far the most limiting nutrient and greater response to applied nutrients is expected in maize than rice, possibly due to a combined effect of higher yield potential in maize and the change from puddled submergence conditions in rice to a more aerobic ecology in maize. Data from another set of multiple location SSNM experiments in two major maize-based cropping systems, i.e. maize-wheat and rice-maize in India (Timsina et al., 2010) showed significant yield improvement of maize under SSNM compared to general recommendations. Omission plot yield data revealed differential indigenous nutrient supplying capacity of the study sites across locations (agro-ecologies) and the authors suggested that response to applied nutrients as well as off-take of nutrients over a cropping season must be included as criteria to develop recommendations under no or limited response scenarios.

Effects of omission of P and K are shown in these photos from maize plots.

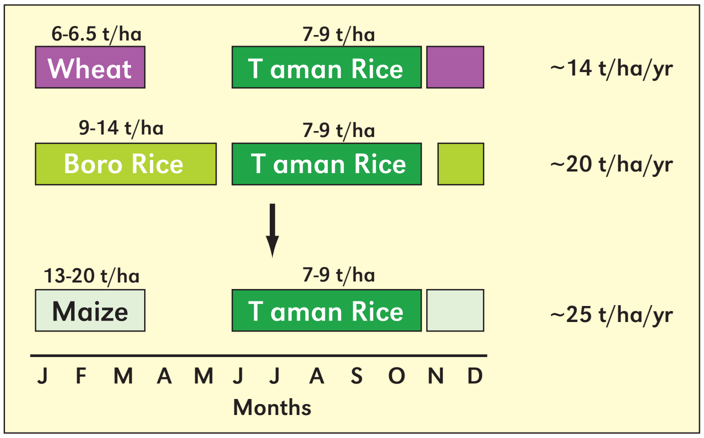

Figure 1. Potential grain production of rice-based cropping systems in Dinajpur, Bangladesh.
Source: Pasuquin et al. 2007

In two districts of northwest Bangladesh, grain yield data from on-farm SSNM trials with rabi maize show large yield responses to N addition **(Table 1)** (Timsina et al., 2010). Yields in the nutrient omission treatments varied widely across farmer fields within a district and also differed in the two districts, indicating large variations in the indigenous nutrient supplying capacities of the soils. Yields in the minus N treatment were low. However, in low P and low K treatments they were quite close to the sufficient yields achieved in the NPK treatment indicating large response to added N, but low response to added P and K due to variation in indigenous soil nutrient supply.

Table 1. Grain yield (t/ha) of winter maize from on-farm SSNM experiments in Bangladesh.

Treatments	Rangpur	Rajshahi
N omission	0.5 to 5.1	3.4 to 3.9
P omission	3.9 to 8.3	4.5 to 8.5
K omission	4.1 to 8.1	5.3 to 7.9
Low K	5.5 to 8.8	6.2 to 8.9
Low P	5.8 to 9.8	6.5 to 8.6
NPK	6.0 to 10.3	6.7 to 10.3
NPKSZn	6.0 to 10.4	7.2 to 10.8

This high variability in response to applied N, P, and K across agro-ecologies suggests the necessity of SSNM to improve productivity of R-M systems as well as the component crops. Very high yield losses in maize due to N omission might be associated with the loss of SOM due to dry tillage in aerated soil after rice cultivation under submergence (Pampolino et al. 2010), and may need serious consideration for reduced or zero-till cultivation of maize with residue retained from the previous rice crop. Timsina et al. (2010) hypothesized that the establishment of maize after rice with reduced or no tillage, and retention of crop residues, could help conserve SOM and maintain soil fertility provided improved nutrient management is practiced. Experiments are underway in South Asia, particularly in India and Bangladesh, comparing maize and rice under conventional, reduced, and zero tillage in R-M systems to standardise nutrient management practices.

Estimating Fertiliser Needs for R-M Systems

Maize hybrids grown during the winter season in South Asia have an attainable grain yield of 10 to 12 t/ha, with similar non-grain biomass. Such biomass generation can often be associated with removal of 200 kg N, 30 kg P, 167 kg K, and 42 kg S per hectare (BARC, 2005). Studies in R-M systems in

Bangladesh have shown highly negative N and K balance (120 to 134 kg and 80 to 109 kg/ha, respectively) with positive P balance (Ali et al., 2008, 2009). So nutrient requirement of intensive R-M systems must be associated to attainable yield (Yat) levels of the component crops. Buresh and Timsina (2008), using crop simulation models for rice and maize, showed that attainable annual yields were markedly higher for R-M (17.3 t/ ha) than Rice-Rice (R-R) (14.1 t/ha) cropping systems, suggesting much higher nutrient extraction and fertiliser needs for R-M than R-R as these cropping systems approach their Yat. The Yat of maize estimated by the authors (11.1 t/ha) was markedly higher than the currently reported average farmers' yield of 8 t/ha, indicating opportunities for future increases in maize yield through improved crop and nutrient management practices. The estimated yield can subsequently be used to assess evolving fertiliser needs as cropping system diversify, intensify and increase in yield.

Likewise, Pasuquin et al. (2007) demonstrated how diversification from R-R or Rice-Wheat (R-W) systems to R-M systems can impact on nutrient use in Bangladesh. There is no alternative to growing summer rice (T. aman) in the rainy season so the production potential changes depending on the second crop grown. The production potential is highest for R-M systems with about 25 t grain/ha/yr, followed by R-R (20 t/ha/yr) and R-W systems (14 t/ha/yr) **(Figure 1)**. Because crop yield is directly related to the amount of nutrients taken up by a crop, fertiliser consumption is expected to increase when farmers shift from either a R-R or a R-W system to R-M systems due to a greater demand for nutrients at higher production levels. Shifting from one crop to another is likely to have moderate impact on fertiliser demand, while shifting from a single to a double, or from a double to a triple-cropping system, would result in increased fertiliser consumption and demand, as well as increased farmers' productivity.

Future Priorities for Research in Nutrient Management for R-M Systems

As maize cropping becomes more widespread and intensive in South Asia, and particularly in Bangladesh and South India, an emerging issue of great importance is how to sustain the productivity of R-M cropping systems through integrated soil fertility management strategies. Continuous production of high yielding maize will lead to the rapid depletion of mineral nutrients from soil because of the greater nutrient uptake and removal by maize than other cereals such as rice or wheat. SSNM strategies for rice and maize separately have now been well developed (Fairhurst et al., 2007; Witt et al., 2007). Future research and dissemination should now focus on developing SSNM principles for R-M systems considering the yield goals, crop demand, indigenous soil nutrient levels, and residual soil fertility. Decision support systems (DSS) based on developed principles at a later stage would help farmers and extension workers to adopt SSNM strategies for R-M systems. Such DSS, namely Nutrient Manager (Buresh et al., 2010) and Nutrient Expert (Witt et al., 2009), for cereals are in the development and evaluation stage in South Asia.

There is, however, a need to understand more about the extent and rate of nutrient depletion and soil physical degradation in the intensifying R-M systems in South Asia. To push the achieved grain yields even higher up the yield potential curve will require larger amounts of nutrients, their better management and overall soil stewardship. On-farm nutrient management experiments that optimise high-yielding rice/maize crops are required to understand how management of such systems can meet the requirements of rice and maize in South Asia given the generally low fertility soil resource base.

Dr. Timsina (j.timsina@cgiar.org) is Senior Scientist/Cropping System Agronomist with IRRI-CIMMYT. Dr. Jat (m.jat@cgiar.org) is Cropping System Agronomist with CIMMYT. Dr. Majumdar (kmajumdar@ipni.net) is Director, IPNI-South Asia Programme.

This article is a summary adapted by the authors from their paper titled "Rice-maize systems of South Asia: current status, future prospects and research priorities for nutrient management" published in *Plant and Soil*, October 2010, Vol. 335, pp. 65-82, and online by *Plant and Soil* (DOI 10.1007/511104-010-a0418-7) on May 18, 2010.

Dr. Timsina is shown visiting a maize field.

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Site-Specific Nitrogen and Potassium Management for Irrigated Rice in the Cauvery Delta

By R. Rajendran, P. Stalin, S. Ramanathan, and R.J. Buresh

A site-specific nutrient management (SSNM) approach was used to formulate and evaluate improved fertiliser management for irrigated rice in farmer fields of the Cauvery Delta in Tamil Nadu for four consecutive seasons during 2001-03. Yield gain and profitability assessment with leaf colour chart (LCC)-guided N management and deciding fertiliser K rates for improved yields with increased profitability in two contrasting soil types of the Delta were the major outcome of this study.

Tamil Nadu accounts for 8.5% of India's total rice production and the Cauvery Delta is the major rice producing zone within the State. Two rice crops are typically grown each year in cropping systems of either rice-rice-fallow or rice-rice-pulses, depending on the availability of irrigation water. The first rice crop, with highest yield potential, is cultivated in Kuruvai, the pre-monsoon dry season (June-September), with predominantly short duration varieties and a plant population of 66 hills/m^2. The second rice crop is grown in Thaladi, the wet season (October-February), with medium duration rice varieties and a planting density of 50 hills/m^2. The entire delta is categorised into "old" and "new" delta with clay loam to clay soils dominating in old delta and sandy loam to clay loam soils with good drainage characteristics existing in new delta.

Improved productivity under irrigated cropping system is vital for meeting the profitability of rice farmers in the State and SSNM offers significant opportunities in this dimension. Nagarajan et al. (2004) used a 'fixed time-adjustable dose approach' of N management and compared the performance of SSNM with that of farmer fertiliser practice (FFP), wherein a yield advantage of 0.49 and 0.63 t/ha of rice was observed in old and new delta soils, respectively. In the SSNM approach, top-dressing of N fertiliser was set at critical growth stages and a chlorophyll meter was used to adjust the N fertiliser doses above or below the pre-set times of N application. This study also used remarkably higher fertiliser K rates than the farmer practice or the existing State recommendations. An alternative approach of 'real-time N management" has evolved where farmers have an option of matching the leaf colour at 7 to 10 day intervals using colour panels of LCC and apply N whenever the leaf colour becomes more yellowish-green than a critical LCC value. There is also a need to optimise the K fertiliser rates before providing valid SSNM recommendations to farmers. Therefore, a study was designed to redefine SSNM recommendations for rice farmers of the Cauvery delta with the use of LCC-guided N management, besides confirming the optimum K fertiliser rates.

Field experiments were conducted in four consecutive rice seasons (Kuruvai 2001; Thaladi 2002; Kuruvai 2002; and Thaladi 2003) during 2001 to 2003. Experiments in the old delta were conducted in 14 farmer fields in two villages – namely Ammanpettai and Therazhandur near Aduthurai (11° 1´N, 79° 29´E) – whereas experiments in the new delta were conducted in 15 farmer fields in two villages (Panchanathikkottai and Vandayariruppu) near Tanjavur (10° 47´N, 79° 10´E). The selected sites represented the major soil types of the delta and had ensured irrigation supply for both rice crops. Three treatments were imposed in farmer fields in all four seasons in a completely randomised block design with one set of treatments in a farmer field considered as a replication **(Table 1)**. An additional fourth treatment was also tested during dry season of 2002 and wet season of 2003.

The P and K fertiliser rates in the SSNM treatments were determined as outlined by Witt et al. (2002). Phosphorus rates were not considered as experimental variables as the soils are moderately high in extractable P and application rates commonly used by farmers are already near the recommended levels. Thus, in any given season and site, the P rate was equal for all SSNM treatments. However, K rates were differentiated within SSNM low K and SSNM high K treatments to help assess crop response and profitability under higher K rates. These K rates were kept similar in both seasons to examine whether differences in crop performance and profitability between K rates were affected by season. All the P fertiliser and 50% of the K fertiliser were incorporated in the soil immediately before transplanting and the remaining K fertiliser was top-dressed at panicle initiation stage.

In the fixed time-adjustable dose approach, N was applied at pre-set days after transplanting (DAT), and the N doses were adjusted upward or downward from tillering phase based on

Abbreviations: N = nitrogen; P = phosphorus; K = potassium; USD = U.S. dollar.

Table 1. Treatment details for field experiments.

Treatment	Details
T_1	Farmer fertiliser practice, where NPK fertiliser management was done by a farmer without involvement of researcher.
T_2	LCC-based N management by fixed time adjustable dose approach, P rate determined by SSNM approach and K applied at less than an estimated SSNM rate (SSNM-LK). Altogether, P was applied at 10 to 15 kg P/ha in the old delta and 15 kg P/ha in the new delta, whereas K was applied at 30 kg K/ha in the old delta and 40 kg K/ha in the new delta.
T_3	Exactly as T_2, except K was applied at an estimated SSNM rate (SSNM HK), which was 50 and 80 kg K/ha in the old and new delta soils, respectively.
T_4	LCC-based N management by real time approach with P and K management as followed in farmer practice.

Table 2. Effect of site-specific nutrient management on grain yield, plant accumulation of NPK, and profitability of rice-growing farmers of Cauvery delta.

			------ Treatment[2] -----			SSNM LK – FFP		SSNM HK – FFP	
Parameter	Site	Season[1]	FFP	SSNM LK	SSNM HK	Δ	$p > \|t\|$[3]	Δ	$p > \|t\|$
Grain yield, t/ha	Old delta	Dry	5.8	6.3	6.4	0.5	0.001	0.6	< 0.001
		Wet	5.9	6.2	6.3	0.3	0.001	0.4	< 0.001
	New delta	Dry	6.0	6.5	7.0	0.5	0.017	0.9	< 0.001
		Wet	5.6	5.9	6.3	0.4	0.058	0.7	< 0.001
Plant N, kg/ha	Old delta	Dry	103	117	120	14	< 0.001	17	< 0.001
		Wet	102	117	117	15	< 0.001	15	< 0.001
	New delta	Dry	99	105	112	6	0.045	13	< 0.001
		Wet	88	95	101	7	0.048	13	0.001
Plant P, kg/ha	Old delta	Dry	21	22	23	1	0.116	2	0.047
		Wet	22	23	23	1	0.334	1	0.142
	New delta	Dry	26	27	28	1	0.432	2	0.031
		Wet	25	26	27	1	0.330	2	0.017
Plant K, kg/ha	Old delta	Dry	85	98	105	13	< 0.001	20	< 0.001
		Wet	89	97	100	8	0.009	11	< 0.001
	New delta	Dry	84	88	94	4	0.118	10	< 0.001
		Wet	81	84	91	3	0.160	10	< 0.001
GRF[4], USD/ha	Old delta	Dry	649	710	720	61	< 0.001	71	< 0.001
		Wet	646	691	695	45	< 0.001	49	< 0.001
	New delta	Dry	674	730	769	56	0.015	95	< 0.001
		Wet	612	658	692	46	0.065	80	0.001

[1] Dry, two dry season crops; Wet, two wet season crops.

[2] FFP, farmer fertiliser practice; SSNM LK, site-specific nutrient management with low K rate; SSNM HK, SSNM with high K rate

[3] Probability of a significant difference between two treatment means.

[4] GRF, gross return above fertiliser cost.

a LCC reading taken for the youngest fully developed leaf immediately before N application. In the dry season, urea was applied at 40, 50, and 30 kg N/ha at about 15, 28 to 32, and 45 to 50 DAT, whereas, in the wet season, urea was applied at 30, 40, 40, and 10 to 15 kg N/ha at about 15, 30, 45-50, and 60 to 70 DAT, respectively. For the real-time N management, LCC readings were taken at 10-day intervals starting from about 14 DAT to heading. Urea was applied at 35 kg N/ha in the dry season and 30 kg N/ha in the wet season whenever the average LCC reading fell below 4.

Crop management at all experimental fields was completely monitored by farmers. Plant samples were collected from 12 hills at physiological maturity and growth parameters were recorded and nutrient concentrations in grain and straw were determined. Grain yields were recorded from a 5 m^2 harvest area in the centre of each plot at harvestable maturity and reported at 14% moisture. The agronomic efficiency (AE_N) and partial factor productivity (PFP_N) for applied N fertiliser were calculated following Cassman et al. (1998).

Grain yield increased significantly across seasons and sites with both SSNM low K (average = 0.43 t/ha) and SSNM high K (average = 0.65 t/ha) as compared to FFP **(Table 2)**, but the difference was more evident within the new delta sites (mean = 0.63 t/ha) than the old delta sites (mean = 0.45 t/ha). The yield increase with SSNM, which corresponded to 7% at low K and up to 12% with high K, was associated with increased panicle number (+5%) over FFP (data not shown) and higher plant accumulation of N, P, and K at maturity **(Table 2)**, which was comparable to the 8 to 13% yield increase with SSNM reported by Nagarajan et al. (2004). Grain yields were higher in the dry season than the wet season in the new delta, but not in the old delta ($p = 0.021$ for site x season interaction).

The relatively higher plant accumulation of N and K in the old versus the new delta across FFP and SSNM treatments did not translate into higher yields in the old delta **(Table 2)** as the internal efficiencies of N and K use were consequently higher in the new delta. This is evident from the fact that in SSNM high K, the average internal N use efficiency (kg grain/kg plant N) was 54 and 62 in the old and new deltas, whereas, the internal K use efficiency (kg grain/kg plant K) was 62 and 72 in the old and new deltas, respectively. Plant accumulation of P was higher with SSNM high K than FFP even though P fertiliser use was lower with SSNM than FFP **(Table 2)**. Further, plant P was significantly lower ($p < 0.001$) in the old versus new delta. However, the low average internal P use efficiency (277 kg grain/kg plant P) in the old delta, relative to other reports of 385 kg grain/kg plant P for balanced nutrition (Witt et al., 1999), suggests that P was not limiting in this region.

The gross return above fertiliser cost (GRF) increased with SSNM over FFP at both sites **(Table 2)** and profit for SSNM was higher with both options in the old delta; however in the new delta, profit was only improved with SSNM high K during the dry season. The increased profit with SSNM as compared to FFP was attributed to additional returns arising from higher yields with SSNM **(Table 2)**. The profit (ΔGRF) with SSNM high K (50 kg K/ha) as compared to SSNM low K (30 kg K/ha) in the old delta was negligible (mean = USD 7/ha) and not significant. In the new delta, however, the use of more K increased grain yield (mean = 0.4 t/ha) and profit (mean = USD 36/ha) in both seasons. Participating

Yields obtained in SSNM plots are compared to results from FFP plots by weigh-scale.

farmers in the new delta used, on average, 37 kg K/ha, which corresponded to SSNM low K treatment (40 kg K/ha). Consequently, our results indicate a clear benefit from greater use of K fertiliser by farmers in the new delta soils. The current recommendation of the extension service, which promotes uniform K fertiliser management throughout the Cauvery delta, should be revised to provide different recommendations for the old and new delta soils.

LCC-Guided N Management

A comparison of the agronomic and economic performance between the LCC-based real-time N management (RTN) and FFP is shown in **Table 3**. Use of LCC-RTN significantly increased grain yield (0.3 to 0.5 t/ha) in both seasons within the old and new delta soils. Further, N management with LCC significantly increased N fertiliser use in the old delta but not in the new delta ($p < 0.001$ for site and treatment), even though fertiliser use under FFP was already higher in the old delta. However, agronomic efficiency of N fertiliser consequently increased in the new delta as a result of increased grain yield without a corresponding increase in N fertiliser use **(Table 3)**.

Use of LCC for N management was profitable across all seasons and sites. Profit, as determined from the difference in GRF between RTN and FFP, averaged USD 58/ha in the old delta and USD 33/ha in the new delta. The increased profit was due to an increase in yield rather than a reduction in N fertiliser use **(Table 3)** and yield increase with LCC was further attributed to a change in timing of N fertiliser application to better match the crop needs for additional N (data not shown). Rice crops generally need higher N levels during active tillering (AT) to panicle initiation (PI) stage and LCC based RTN recommends mostly 50% of total N application during this period. However, in FFP, lesser N (20 to 30% of total N) was only applied during this critical period while more N (30 to 35% of total N) was applied as basal before planting of rice, which was nil in the case of LLC-based RTN. In FFP, N fertiliser was applied basally in both seasons. However, with the use of LCC, basal N application was skipped and delayed until 14 DAT and applied during the critical growth stages of AT and PI when crop demand for N was high. Thus, better timing and splitting of N fertiliser applications using LCC-based RTN proved to be beneficial to increase the yield and profitability of rice farmers.

Table 3. Effect of real-time N management using LCC on grain yield, N fertiliser use, N use efficiency, and economics of rice farmers.

			Treatment[2]		RTN – FFP	
Parameter	Site	Season[1]	FFP	RTN	Δ	$p > \mid t \mid$[3]
Grain yield, t/ha	Old delta	Dry	5.9	6.4	0.5	< 0.001
		Wet	6.0	6.3	0.3	< 0.001
	New delta	Dry	5.8	6.2	0.3	< 0.001
		Wet	5.9	6.2	0.3	< 0.001
N fertiliser, kg/ha	Old delta	Dry	119	140	21.0	< 0.001
		Wet	131	150	19.0	< 0.001
	New delta	Dry	104	105	1.0	0.896
		Wet	101	104	3.0	0.746
AEN[4], kg/kg N	Old delta	Dry	18	19	1.2	0.246
		Wet	20	19	-0.5	0.612
	New delta	Dry	11	15	3.2	0.001
		Wet	15	17	1.2	0.206
GRF[4], USD/ha	Old delta	Dry	654	722	68	< 0.001
		Wet	655	703	48	< 0.001
	New delta	Dry	646	678	32	0.005
		Wet	653	686	33	< 0.001

[1] Dry, one dry season crop; Wet, one wet season crop.
[2] FFP, farmer fertiliser practice; RTN, LCC-based real-time N management with farmer PK fertiliser practice.
[3] Probability of a significant mean difference between RTN and FFP.
[4] AEN, agronomic efficiency of N fertiliser; GRF, gross return above fertiliser cost.

Conclusions

The findings from the above studies suggest that the improved N management with LCC consistently increased yield and profit as compared to FFP, when the supply of K fertiliser was sufficient. This approach should be promoted throughout the Cauvery delta for harnessing higher profits. Existing P fertiliser recommendation of 22 kg P/ha in the dry season and 26 kg P/ha in the wet season may be reduced to about 15 kg P/ha. In the old delta, application of 30 kg K/ha in each season (which was nearer to the common farm practice) was sufficient. Grain yield and profitability were higher with 80 than 40 kg K/ha in the new delta. Thus, it is not possible to determine the optimum K rate from our study, but farmers of new delta should be targeted for promoting additional use of K fertiliser. The SSNM approach used for improving fertiliser recommendations at the experimental villages in this study can now be promoted and used throughout the Cauvery delta and irrigated rice zones in southern India.

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Fertilising for Sustainable Onion Production Systems

By Ethel Ngullie, V.B. Singh, A.K. Singh, and Harmandeep Singh

Studies evaluated straight versus combined applications of manures, fertilisers, and microbial biofertilisers with reference to onion bulb yield and soil nutrient balances. Given the good supply of quality manures, observations favored the combined application of inorganic fertilisers and manures over sole application of either nutrient source. Application of 50 to 75% of the fertiliser recommendation plus any microbial inoculant treatment failed to achieve a viable alternative.

Onion (*Allium cepa* L) is a highly nutrient-responsive crop. Conventional methods of fertilisation have undoubtedly helped in improving both bulb yield and quality. But lately, routine management practices in India appear to be incapable of maintaining yields over the long-term. The steady depletion of native soil fertility and the occurrence of multiple nutrient deficiencies in onion fields has led to the identification of nutrient management as a key factor limiting sustainable onion production (Sharma et al., 2003). Integrated nutrient management (INM) offers an effective strategy (Dimri and Singh, 2005; Santhi et al., 2005).

Although the use of manures as nutrient sources for vegetables is common, their effectiveness is potentially limited by nutrient release patterns that are often out of synchrony with crop demand, large variability in source quality and field distribution, and food safety. All of these issues have contributed to experimentation with alternative options. A gradual shift from using purely organic sources to introducing some proportion of inorganic fertilisation is gaining acceptance. This shift has formed the basis for INM, which could involve three nutrient sources: microbial inoculants or biofertilisers including azotobacter (Az), azospirillum (Azr), and phosphate solubilising bacteria (PSB), inorganic fertilisers, and manures. However, INM further prescribes that selected nutrient inputs be used judiciously to ensure optimum supply of all essential nutrients for sustained crop production. Most INM studies conducted with onion have lacked the experimental components required to link soil nutrient budgeting with bulb yield response.

This field experiment was carried out with two major objectives: 1) determine the magnitude and economic value of responses of onion to INM-based treatments, and 2) assess the nutrient uptake pattern to determine net changes in the soil nutrient balance sheet.

The experiment was conducted during the kharif (monsoon) seasons between 2007-09 at the experimental farm (25°45'43" N latitude - 93°53'04" E longitude) of the School of Agricultural Sciences and Rural Development (SASRD), Nagaland University, Medziphema, Nagaland to study fertilisation strategies for sustainable onion (var. Agrifound Dark Red) production. The experimental soil was classified as Typic Rhodustalf with a loam texture (58% sand, 20% silt, and 21% clay), pH 5.2 (1:2), high organic carbon (21.8 g/kg by Walkley and Black method), low available N (248 kg/ha by alkaline permanganate distillation method), low available P (11 kg P_2O_5/ha by Bray's method), and low available K (178 kg K_2O/ha, ammonium acetate extractable) (Sparks, 1996).

Combined application of inorganic fertilisers with organic manures offers better results in onion production in India.

Table 1. Response of different INM-based treatments on the onion bulb yield (fresh weight basis).

Treatments	----- Bulb yield, t/ha ----- 2007-08	2008-09	Mean
T_1 = Control	2.80	2.60	2.70
T_2 = Current recommendation (RDF)	3.32	3.80	3.56
T_3 = FYM	3.10	2.94	3.02
T_4 = Pig manure (PiM)	3.18	3.04	3.11
T_5 = Poultry manure (PM)	3.10	3.50	3.30
T_6 = Vermicompost (Vm)	3.60	3.46	3.53
T_7 = 50% RDF + 50% FYM	3.70	3.98	3.84
T_8 = 50% RDF + 50% PiM	3.50	3.80	3.65
T_9 = 50% RDF + 50% PM	3.40	3.96	3.68
T_{10} = 50% RDF + 50% Vm	3.91	4.19	4.00
T_{11} = 50% RDF + Az	2.81	3.01	2.91
T_{12} = 50% RDF + Azr	2.92	2.76	2.84
T_{13} = 50% RDF + PSB	2.72	2.92	2.82
T_{14} = 75% RDF + Az	2.98	3.04	3.01
T_{15} = 75% RDF + Azr	3.00	3.16	3.08
T_{16} = 75% RDF + PSB	3.18	3.06	3.12
CD (p = 0.05)	0.12	0.18	0.15

Abbreviations: N = nitrogen; P = phosphorus; K = potassium; SSP = single superphosphate; KCl = potassium chloride; RDF = recommended dose of fertilization; FYM = farmyard manure; PiM = pig manure; PM = poultry manure; Vm = vermicompost; CD = critical difference, equivalent to Least Significant Difference. INR = Indian rupee (USD 1 = approximately INR 44.41).

Table 1 outlines 16 treatments that were replicated three

Table 2. Balance sheet for nutrient input and output for onion in response to INM treatments (mean of two seasons).

	Nutrient addition, kg/ha			Nutrient removal, kg/ha			Net balance, kg/ha		
Treatments	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
T_1	-	-	-	45 (1.68)[1]	25.2 (0.40)	32.4 (0.98)	-45	-25.2	-32.4
T_2	100	60	60	79 (2.22)	45.8 (0.57)	52.8 (1.24)	21	14.2	7.2
T_3	104	23	162	56 (1.86)	29.8 (0.44)	37.2 (1.02)	48	-6.8	124.8
T_4	109	18	95	61 (1.96)	36.6 (0.50)	44.4 (1.20)	48	-18.6	50.6
T_5	107	25	91	63 (1.90)	34.3 (0.44)	49.2 (1.12)	44	-9.3	41.8
T_6	102	18	74	75 (2.12)	41.2 (0.50)	48.0 (1.14)	27	-23.2	26
T_7	106	72	141	74 (1.92)	41.2 (0.46)	50.4 (1.10)	32	30.7	90.7
T_8	105	70	108	74 (2.02)	43.5 (0.51)	54.0 (1.24)	31	26.1	53.5
T_9	104	69	97	73 (1.98)	41.2 (0.48)	51.6 (1.16)	31	27.4	45.6
T_{10}	101	73	106	96 (2.40)	52.7 (0.58)	64.8 (1.34)	5	19.9	40.8
T_{11}	70	69	36	51 (1.76)	29.8 (0.44)	36.0 (1.02)	19	39.2	0
T_{12}	75	69	36	49 (1.72)	27.5 (0.43)	50.4 (1.88)	26	41.5	-14.4
T_{13}	50	114	36	50 (1.78)	29.8 (0.46)	37.2 (1.11)	0	84.2	-1.2
T_{14}	95	69	36	55 (1.82)	32.1 (0.46)	40.8 (1.14)	40	36.9	-4.8
T_{15}	100	69	36	56 (1.83)	34.3 (0.48)	43.2 (1.18)	44	34.7	-7.2
T_{16}	75	114	36	57 (1.84)	34.3 (0.49)	67.2 (0.18)	18	79.7	-31.2
CD ($p = 0.05$)	-	-	-	5.4 (0.12)	2.5 (0.03)	4.6 (0.16)	-	-	-

[1] Figures in parentheses represent nutrient concentration in %.

times and tested in a randomised complete block design. Full rates for the FYM (0.8% N, 0.08% P, 1.04% K), PiM (1.82% N, 0.14% P, 1.32% K), PM (2.14% N, 0.22% P, 1.52% K), and Vm (2.04% N, 0.15% P, 1.24% K) were designed to supply approximately the same N (100 kg N/ha) provided by the RDF treatment and were calculated to be 13 t, 6 t, 5 t, and 5 t/ha, respectively. The combined manure + fertiliser treatments were also designed to supply approximately 100 kg N/ha. Inorganic fertilisers sources were urea, single superphosphate (SSP), and potassium chloride (KCl). The anticipated nutrient to be added through the Az, Azr, and PSB biofertilisers was credited to the different treatments as 20 kg N, 25 kg N, and 20 kg P_2O_5/ha, respectively.

Each treatment received its entire dose (rate) of manure each year at the time of land preparation. The full dose of P, K, and half dose of N were applied each year at the time of planting and the remaining half dose of N was applied 30 days after planting. For the biofertilisers, the bulblets were dipped in treatment slurries at the rate of 10 g/kg bulblets and then dried under shade before planting. Experimental plots were treated with *Trichoderma* to minimise the incidence of damping-off disease. The bulblets were planted on raised beds during the first week of September and harvested in the first week of January in both the seasons.

The bulbs were harvested after more than 50% of leaves dropped down, and bulb fresh weight was measured. The bulbs were dried in shade, then chopped off and dried at 63 °C ± 2 °C, finely ground, and samples were digested in a 3:1 di-acid mixture of H_2SO_4 and $HClO_4$. In these acid extracts, nutrients were determined as per standard procedures including N by steam distillation using the micro-Kjeldahl method, P by colorimeter using the vanadomolybdophosphoric acid yellow color method, and K by flame photometer (Page et al., 1982). Nutrient budgets were calculated on the basis of nutrient inputs minus nutrient removal by onion bulbs.

Treatments supplying inorganic fertilisers and organic manures, either alone or in combination, generated a significant bulb yield response in both seasons over the control **(Table 1)**. Bulb yields were significantly correlated with bulb uptake of N ($r = 0.732$, $p = 0.01$), P ($r = 0.612$, $p = 0.01$), and K ($r = 0.405$, $p = 0.05$). Data averaged over the two seasons revealed VM to be the only manure source able to produce, by itself, bulb yields that were equivalent to those under the RDF. The best bulb yield responses were achieved with 50% RDF+Vm followed by 50% RDF+FYM. On the contrary, biofertilisers were unable to compensate for reduced application rates of inorganic fertiliser. The use of biofertilisers along with 50% or 75% RDF resulted in bulb yield averages that were at best equivalent to the poorer performing manure sources and in some cases were indistinguishable from the control. The positive performance of the reduced rate of inorganic

Scene at the National Research Center for Onion and Garlic in Pune, India.

Table 3. Economics of different INM-based treatments for Kharif onion production.

Treatments	[1]Cost, 000' INR/ha	[2]Benefit, 000' INR/ha	Net return, 000' INR/ha
T_1	2.50	54.00	51.50
T_2	10.28	71.20	60.92
T_3	20.00	60.40	40.40
T_4	25.00	62.20	37.20
T_5	20.00	66.00	46.00
T_6	11.00	70.60	59.60
T_7	15.14	76.80	61.66
T_8	17.64	73.00	55.36
T_9	10.64	73.60	62.96
T_{10}	15.94	80.00	64.86
T_{11}	8.14	58.20	50.06
T_{12}	8.14	56.80	48.66
T_{13}	8.64	56.40	47.76
T_{14}	9.46	60.02	50.56
T_{15}	9.46	61.60	52.14
T_{16}	9.96	62.40	52.44

[1] Cost of treatments based on price of urea at INR 5/kg, SSP at INR 8/kg, KCl at INR 40/kg, PiM, PM and Vm at INR 2/kg, FYM at INR 1/kg, Azr and Azo at INR 50/kg, and PSB cultures at INR 100/kg. It also includes operational charges covering labor charges for land preparation and two weedings at INR 5,000/ha.

[2] Benefit based on minimum farm rate of onion at INR 20/kg.

fertilisation plus either Vm or FYM does highlight the value of good manure sources as a supplement to inorganic fertilisers. Mineralisation of manures aids in soil nutrient buildup that in turn leads to improved nutrient availability to the growing crop (Singh et al., 2001).

Nutrient removal under the RDF treatment was hard to distinguish from that measured under any manure treatment **(Table 2)**. A comparison of the effect of combining inorganic fertilisers with manures versus their co-application with selected biofertilisers found significantly higher nutrient uptake with the former compared to the latter. As little as 25% of the RDF could not be replaced through biofertiliser supplementation, but up to 50% of the RDF could be effectively replaced with selected manures. The treatment with 50% RDF+Vm observed the highest average nutrient removal of 96-53-65 kg N-P_2O_5-K_2O/ha.

Considering the net nutrient balances presented, the current inorganic fertilisation recommendation maintained a surplus stock of nutrients over 2 years of study **(Table 2)**. All manure treatments developed P deficits, while the treatments with 50 to 75% RDF treatments used in combination with biofertilisers generated small to moderate K deficits. Treatments providing inorganic fertilisers and manure resulted in no deficit for any of the three primary nutrients.

Economic analysis highlighted that sole reliance on manures is not a cost-cutting measure, but favorable changes in soil quality likely compensate for additional costs per hectare through improved long-term nutrient turnover due to the organic amendments. However, net returns per treatment further substantiated the superiority of any combined fertiliser/manure application compared to a fertiliser or manure application at the rates examined **(Table 3)**.

Onion growers in this region often prefer organic manuring over inorganic fertilisation. As is indicated above, this preference is suggested to be a major cause of concern for the spread of multiple nutrient imbalances. Given the good supply of quality manures, our observations favored the combined application of inorganic fertilisers and manures over sole application of either nutrient source. This is a strategy capable of considering the sustainability of onion productivity as well as the preference to maintain a strong dependence on regional sources like FYM.

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Delineation of Productivity Zones in Mandarin Orchards Using DRIS and GIS

By A.K. Srivastava, Shyam Singh, S.N. Das, K.N. Tiwari, and Harmandeep Singh

A survey of seven states in northeast India superimposed the spatial distributions of orchard yield data with leaf analysis data using geographic information system (GIS) technology to delineate important productivity zones within the region.

It is well recognised that crop behavior and soils are not uniform within an orchard (Srivastava et al., 2006). Precision citrus farming involves assessing and managing spatial variability in the supply of nutrients from soil and yield response, thus helping to identify nutrient constraints, rationalise nutrient use, and optimise factor productivity. Advances in software-aided decision support systems (DSS), such as Diagnosis and Recommendation Integrated System (DRIS) and GIS, have led to the development and use of new variability assessment, interpretation, and management tools. These tools have much wider application potential (Schumann and Zaman, 2005; Zaman and Schumann, 2006) when compared with the more empirical approach that growers generally take by improving drainage and fertiliser management.

Table 1. DRIS-based leaf nutrient optima in relation to fruit yield for ‘Khasi’ mandarin grown in northeast India.

	Indices				
Nutrients	Deficient	Low	Optimum	High	Excess
N, g/kg	< 16.7	16.7 - 19.6	19.7 - 25.6	25.7 - 28.5	> 28.5
P, g/kg	< 0.6	0.6 - 0.8	0.9 - 1.0	1.1 - 1.3	> 1.3
K, g/kg	< 5.2	5.2 - 9.8	9.9 - 19.3	19.4 - 24.0	> 24.0
Ca, g/kg	< 17.2	17.2 - 19.6	19.7 - 24.9	25.0 - 27.5	> 27.5
Mg, g/kg	< 1.4	1.4 - 23.0	2.4 - 4.8	4.8 - 5.4	> 5.4
Fe, mg/kg	< 23	23 - 84	84 - 249	249 - 331	> 331
Mn , mg/kg	< 19	19 - 42	42 - 88	88 - 111	> 111
Cu, mg/kg	< 2	2	2 - 14	14 - 21	> 21
Zn, mg/kg	< 11	11 - 16	16 - 27	27 - 32	> 32
	Very low	Low	Good	High	Very High
Productivity, kg/tree	< 19	19 - 32	32 - 56	56 - 69	> 69

A survey of 108 ‘Khasi’ mandarin orchards was carried out between 2002 and 2006 covering 590 km^2 from 50 geo-referenced collection sites in seven states of northeast India (Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, and Tripura). Soils of the region are predominantly Entisols (Haplaquent, Ustifluvent, and Udifluvent), Inceptisols (Ustochrept and Haplaquept), Alfisols (Rhodustalf, Paleustalf, Haplustalf, Orchraqualf, and Rhodustalf), and Ultisols (Palehumult, Haplustult, Plinthaqult,and Plinthustult). Climate is characterised by mean annual rainfalls of 180 cm with mean summer and mean winter temperatures of 28 °C and 15 °C, respectively.

Six-to-seven month old leaves at second, third, or fourth leaf positions from non-fruiting terminals and covering 2 to 10% of trees at a height of 1.5 to 1.8 m from the ground were sampled and analysed for macronutrients (N, P, K, Ca, and Mg) and micronutrients (Fe, Mn, Cu, and Zn). DRIS (Srivastava and Singh, 2008) and GIS (Arc 9.3) were used to delineate major productivity zones represented by the sampled mandarin orchards.

Leaf Nutrient Optima

Large variability in leaf macronutrient content (g/kg) exists across northeast India. For example, N in leaves varied from 20.5 to 26.5 (median 24.7), P from 0.9 to 1.3 (median 1.1), K from 11.2 to 21.3 (median 14.3), Ca from 18.2 to 24.2 (median 19.8), and Mg from 2.2 to 4.2 (median 3.4). Similarly, leaf micronutrient content (mg/kg) varied from 133.5 to 281.2 for Fe (median 138.9), 51.6 to 100.3 for Mn (median 60.2), 5.1 to 22.4 for Cu (median 8.5), and 14.5 to 25.6 for Zn (median 25.5). Using this data, leaf nutrient optima for different nutrients were developed using DRIS-based software **(Table 1)**.

Precision management techniques are being adapted in citrus production.

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

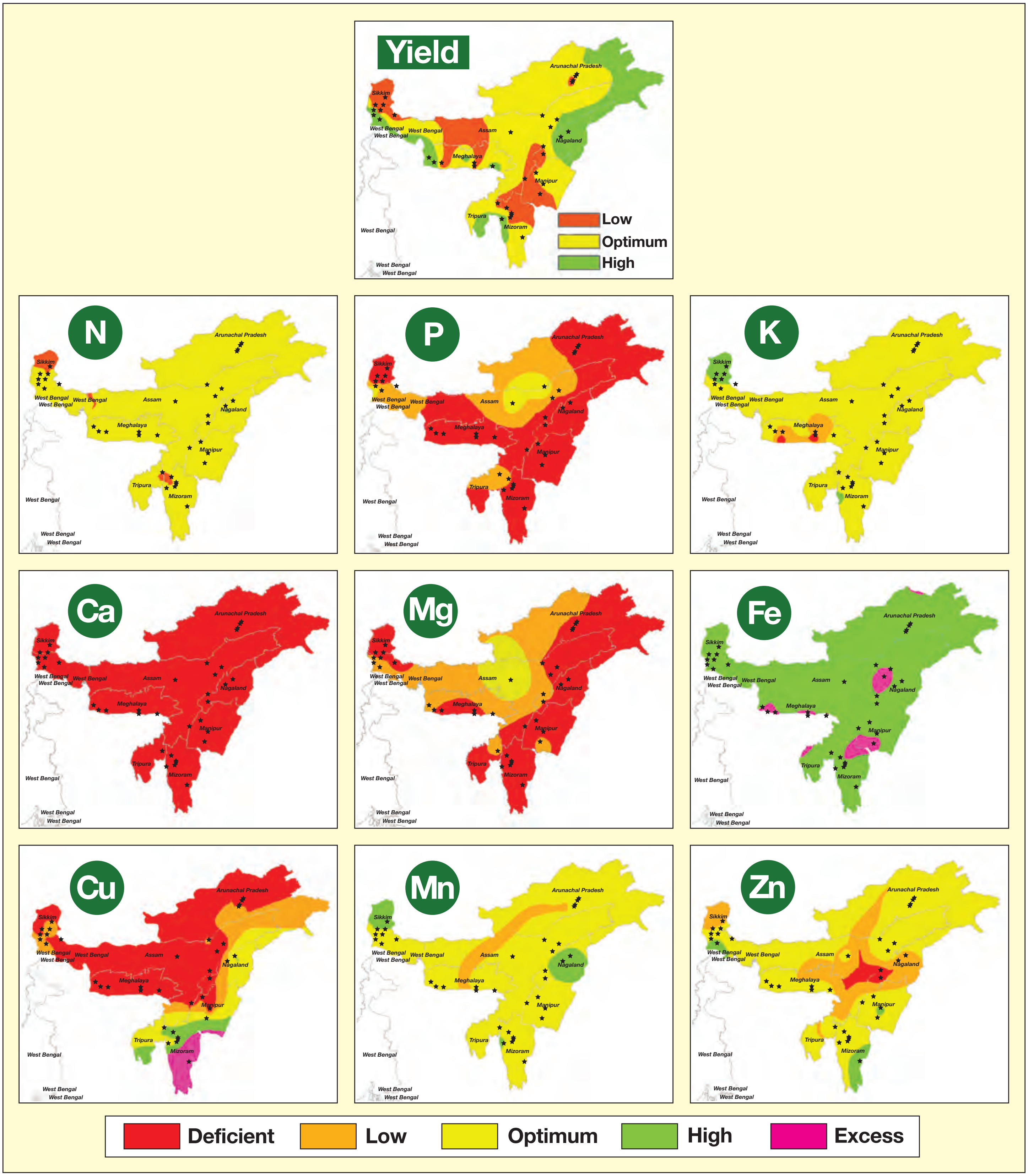

Figure 1. Spatial distribution of 'Khasi' Mandarin yield (productivity) and several leaf nutrients across seven states in northeast India.

Spatial Distribution of Nutrient Constraints

Leaf nutrient optima values were used to develop GIS-based nutrient distribution maps **(Figure 1)**. These maps showed that most orchards in northeast India were optimum in N nutrition, low to deficient in P, and optimum to high in K. Calcium and Mg were largely deficient in the acidic soils. On the other hand, Fe was mostly high, Cu was mostly deficient, and Mn and Zn were mostly optimum.

Delineation of Productivity Zones

Using GIS again, the spatial distribution of selected macro- and micro-nutrient constraints were superimposed and, when combined with fruit yield data, delineated orchard productivity zones of interest **(Figure 2)** including Zone I: 26°8' 13" E & 27°25' 43" E latitude and 92°23' 82" N and 92°59'43" N longitude showing no constraint of Zn, Mg, P, and N and having very high average productivity of 84 kg/tree (areas identified as Navgaon, and Rangpara of Assam state); Zone II: 26°31'35"-27°2'35" E latitude and 88°3'49"-88° 23' 56" N longitude; 26°35'56"-27° 27'3" E latitude and 93° 23' 5"-93° 58' 26" N longitude showing no constraint of Zn, P, and N and having an good productivity of 54 kg/tree (areas identified as Golpara of Assam state and Mirik, and Lisa Hills of West Bengal state); and Zone III: 26°4' 55"-27°47'43" E latitude and 91°32'8"-93°0' 47" N longitude showing no constraint of Zn and P and having low productivity of 30 kg/tree (areas identified as Shergaon, Dirang, and Tangla & Mangaladai (Assam).

In summary, the integrated use of two diverse software-based DSS helped in identifying potential sites for the purposes of land use planning and monitoring trends in productivity and orchard fertility. Future evaluation of these productivity zones/sites with respect to maximising productivity and improving sustainability will help to improve the efficacy of this delineation process.

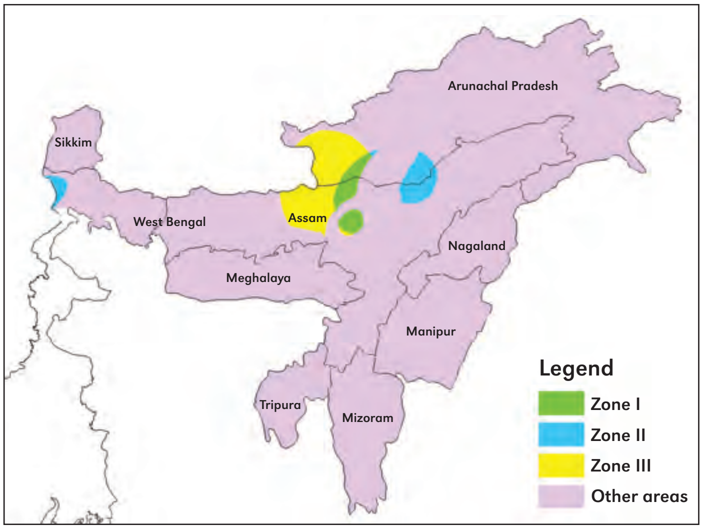

Figure 2. Three selected zones of mandarin orchard production in northeast India differentiated by selected leaf nutrient and yield survey data.

Software-aided decision support systems are adaptable to mandarin orchard management in Northeast India.

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International Certified Crop Adviser Program Now in India

The International Certified Crop Adviser (ICCA) program of the American Society of Agronomy (ASA) was launched in India during 2010.This proactive certification program was established in 1991 in the United States of America (USA) and later extended to Canada. India is the first country outside North America to provide the ICCA program, along with "continuing education" as a major, significant, and attractive feature for renewing the certification. The India ICCA program is one of the objectives of the Cereal System Initiative for South Asia (CSISA). The program is being adapted in India through collaboration of ASA with the International Rice Research Institute (IRRI) and Indian Society of Agribusiness Professionals (ISAP).

The India ICCA certificate will be issued by ASA and will be recognized in the USA, Canada, and India. The program is open for all agri-professionals and agri-graduates who are engaged in farm advisory activity, whether in private or public sectors. The certification program includes af a comprehensive exam based on the Performance Objective document (syllabus) covering four major competency areas: Nutrient Management, Soil and Water Management, Integrated Pest Management, and Crop Management.

The main objective of this program is to educate the frontline agriculturists employed by private companies, non-government organizations (NGOs), and public sectors to guide farmers on the latest technologies. With this objective, the India ICCA program aims at improvement in the quality of farm advisory across all sectors of agriculture. The exam will be offered twice every year, in June and December. The basic requirement for the certification is either a degree in Agriculture, B.Sc. (Agri.) with a minimum of 2 years of crop advising experience or a higher secondary (10 +2) with a minimum of 4 years of active crop advising experience.

Detailed information for prospective candidates regarding the India ICCA exam is available at the website: www.certifiedcropadviser.org/india. Candidates may also contact the Manager, India Certified Crop Adviser Program, through e-mail at k.yadav@cgiar.org or phone at + 91 – 9654456005. Or contact the Indian Society of Agribusiness Professionals by phone at +91-11-43154100 or e-mail at indiacca@isapindia.org.

KERALA, INDIA

Evaluation of Different Nutrient Management Options for Leaf Yield, Quality, and Economics of Betel Vine Cultivation

By Usha C. Thomas, S. Chandini, S. Anil Kumar, Allan Thomas, and T. Satyanarayana

Betel vine is one of the most profitable intercrops cultivated in the small holdings of Kerala. Complete reliance on chemical fertilisers without inclusion of organic sources of nutrients had some adverse effects on keeping quality and chewing properties of leaves, in addition to aggravating foliage diseases. Thus, a 2-year study was conducted in order to identify rational options for substituting chemical fertilisers with organic nutrient sources for improved productivity and better chewing quality of betel vine.

Betel vine (*Piper betel* L.), a native of Malaysia, is a perennial dioecious creeper that possesses a host of medicinal properties. Though the crop demands continuous care and monitoring by farmers, it is considered as one of the most profitable intercrops cultivated in the home gardens of Kerala.

Nitrogen plays a direct role on growth, yield, and keeping quality of betel vine leaves. A study conducted at College of Agriculture, Vellayani, showed that bulky organic manures can be partly replaced by chemical fertilisers without affecting the chewing quality of leaves (Chandini, 1989). Maiti et al. (1995) reported that application of 200 kg N/ha through a 1:1 ratio of organic and inorganic sources was the best way for obtaining higher yields of betel vine. Debanath et al. (1985) reported that integrated nutrient management (INM) is always advantageous from a long-term perspective both in terms of cost of production and soil health. Thus, a field study was undertaken in Thiruvananthapuram district at the College of Agriculture, Vellayani, to develop an INM practice for improved productivity and quality of betel vine.

Field experiments were conducted during the main planting season starting from June to August in 2001-02 and 2002-03. The soil was an acidic, red loam, low in available N and K, and medium in available P status. The most popular local cultivar (Cheelanthikarpuram) was selected for the study. Its leaves are dark green, broad, and coarse-textured with good storage quality. Chandini (1989) recommended that 60 kg N and 25 kg P_2O_5/ha, over a basal dose of 30 t/ha of FYM, was an acceptable rate of nutrients for this crop. Along with the results of Maiti et al. (1995) reported above, these results formed the basis for deciding N levels in this study.

The treatments involved two N levels (60 and 90 kg/ha), three organic sources: 1) poultry manure (PM), 2) farmyard manure (FYM), and 3) neem cake (NC) – a by-product obtained in the process of cold pressing Neem tree fruits and kernels. The treatments also included two source substitution ratios (1:1 and 2:1). Phosphorus was applied as Mussoriephos (20% P_2O_5) rock phosphate at 30 and 45 kg P_2O_5/ha and K was applied as potassium chloride (KCl) at 60 and 90 kg K_2O/ha to maintain a uniform treatment ratio of 2:1:2. Both fertilisers and manures were applied in equal splits, at monthly intervals after establishment, as surface bands. A brief description of treatments, arranged in a randomised block design with three replications, is given in **Table 1**. Observations were collected on growth and yield parameters for both years and were analysed using standard statistical tools.

Table 1. Treatment details imposed in the experiment.

Treatments	Manure Source	 kg N/ha	 t/ha	Urea, kg N/ha
T_1	Poultry	30	2.5	30
T_2	Poultry	40	3.3	20
T_3	Farmyard	30	7.5	30
T_4	Farmyard	40	10	20
T_5	Neem cake	30	2	30
T_6	Neem cake	40	2.7	20
T_7	Poultry	45	3.7	45
T_8	Poultry	60	5	30
T_9	Farmyard	45	11.2	45
T_{10}	Farmyard	60	15	30
T_{11}	Neem cake	45	3	45
T_{12}	Neem cake	60	4	30
T_{13}		Farmer practice[1]		

[1] Farmer practice includes 60 t of farmyard manure, 25 t of green manure, and 10 t of wood ash/ha.

P_2O_5 was applied at either 30 or 45 kg/ha, and K_2O at 60 or 90 kg/ha, to maintain a uniform NPK ratio of 2:1:2.

Table 2. Nutrient composition (%) of organic amendments used in the field experiment.

Source	N	P_2O_5	K_2O
Farmyard manure	0.4	0.3	0.2
Poultry manure	1.2	0.63	0.7
Neem cake	1.5	1.0	1.4
Green manure	2.1	0.6	1.0
Wood ash	0.15	2.15	3.0

Abbreviations: N = nitrogen; P = phosphorus; K = potassium; lakh = 100,000; CD = Critical Difference, equivalent to Least Significant Difference; INR = Indian rupee currency code (47 INR = approximately 1 USD).

Across treatments, the average leaf yield increased from 13.8 to 23.7 lakh/ha as the amount of N provided by treatments increased from 60 to 90 kg/ha (**Table 3**). The leaf yield during both years of study revealed that NC + urea applied in a 2:1 ratio (T_{12}) recorded the highest marketable leaf yield compared to other combinations of sources followed by NC + urea applied in a 1:1 ratio (T_{11}). The higher leaf yield with NC over the other two sources could be attributed to its better mineralisation rate and a higher N content (**Table 2**). Regardless, it is inferred that application of 90 kg N/ha through NC and urea in a 2:1 or

1:1 substitution ratio is the best N management schedule for achieving higher leaf yield in betel vine.

Quality of Marketable Leaves

Increasing levels of N application had a significant impact on keeping quality of betel vine leaves, as did the substitution of organic nutrient sources with urea. Farmer practice (FP), with its sole organic N source, provided superior leaf keeping quality followed by NC + urea, and FYM + urea – both applied in a 2:1 ratio at 90 kg/ha total N **(Table 3)**. These observations support the findings of Mandal et al. (1994), who determined that complete reliance on chemical fertilisers without organic input could produce adverse effects through an aggravation of foliage diseases. Supplying N completely through chemical fertilisers generally led to a more rapid release rate for N, producing more succulent leaves and therefore a shorter shelf life. It followed that substitution of inorganic sources with organic fertilisers helped to reduce the N supply rate and provide more appropriate quantities throughout the crop's growth stages.

Sugar and essential oil content are important parameters determining leaf quality in betel vine. Results of the study showed significant influence of INM on essential oil content. Application at 90 kg N/ha (T_7 to T_{12}) recorded the highest essential oil content over N applied at 60 kg/ha (T_1 to T_6) **(Table 3)**. Rahman et al. (1990) reported an increase in essential oil content in coriander seeds with increasing N application from 0 to 60 kg/ha. A comparison among organic sources found equivalent results during 2 years of study if all three sources were applied in a 2:1 combination with urea at a total N rate of 90 kg/ha. Thus, no source had an adverse impact on sugar and oil content and either of the sources can safely be used to substitute, preferably in 2:1 ratio at higher rates of N application, with commercial fertiliser.

Economics of Cultivation

The economics of cultivation were evaluated both in terms of benefit-to-cost ratio (BCR) and net income. Treatments providing 60 kg N/ha generated less favorable economic indicators compared to plots receiving 90 kg N/ha. During the first year, a highest BCR (and income) was obtained with the 2:1 ratio of NC + urea and by NC + urea in 1:1 substitution during the second year – both at 90 kg N/ha **(Table 4)**. This yearly difference follows the observed yield trends. The expenditure for initial crop establishment was higher in the first year than in the second, as was the cost of cultivation, and these factors were reflected in generally lower values for BCR and net income during the first year.

Table 3. Effect of different integrated nutrient management options on yield and quality of betel vine.

Treatments	Marketable leaf yield, lakh/ha	Keeping quality, days for 50% rotting of leaves	Essential oil content, mg/g dry weight	Total sugar, %
T_1	14.52	14.0	0.44	20.68
T_2	12.02	15.7	0.42	20.73
T_3	14.42	15.7	0.45	21.60
T_4	13.95	13.5	0.44	22.75
T_5	15.17	15.3	0.44	23.35
T_6	12.78	14.6	0.46	22.46
T_7	18.67	15.5	0.52	26.54
T_8	20.13	16.7	0.51	27.59
T_9	20.96	14.5	0.51	26.90
T_{10}	24.68	18.0	0.57	29.13
T_{11}	27.30	13.0	0.55	28.55
T_{12}	30.72	18.0	0.55	29.22
T_{13}	19.27	20.5	0.55	25.40
CD	4.88	3.4	0.04	2.53

Table 4. Effect of different integrated nutrient management options on economics of betel vine.

	------ Net income, INR/ha ------			--------- B:C ratio --------		
Treatments	Ist year	2nd year	Average	Ist year	2nd year	Average
T_1	28,587	66,493	47,540	1.27	1.75	1.51
T_2	8,488	20,593	14,541	1.07	2.21	1.64
T_3	51,188	51,393	51,291	1.49	1.59	1.54
T_4	46,088	25,693	35,891	1.41	1.27	1.34
T_5	3,545	58,150	30,848	1.41	2.09	1.75
T_6	15,131	32,564	23,848	1.52	1.02	1.27
T_7	51,638	101,943	76,791	1.44	2.01	1.73
T_8	114,888	44,293	79,591	1.85	1.39	1.62
T_9	76,588	126,993	101,791	1.65	2.28	1.97
T_{10}	99,288	147,093	123,191	1.78	2.3	2.04
T_{11}	105,424	151,429	128,427	2.32	2.91	2.62
T_{12}	132,002	145,807	138,905	2.4	2.63	2.52
T_{13}	92,088	110,593	101,341	1.92	2.34	2.13
CD	-	-		0.04	0.01	

Summary

The results of the present study revealed that the integration of organic sources of nutrients with urea gave the highest yield and strengthens the concept of an integrated plant nutrient management system. It is inferred from this study that application of NC + urea in 1:1 or 2:1 ratios can be considered as economically viable options although an adequate total N rate is critical. The appropriate substitution ratio would be dependent on the regional availability of the source.

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Use of Village-Level Soil Fertility Maps as a Fertiliser Decision Support Tool in the Red and Lateritic Soil Zone of India

By Wasim Iftikar, G.N. Chattopadhayay, K. Majumdar, and G.D. Sulewski

The combined influences of poor infrastructure, high implementation costs, and a diverse mosaic of small holders have limited the effectiveness of soil test-based fertilisation programs in South and Southeast Asian countries. Geographic information system (GIS)-based fertility maps represent an alternative decision support tool and this village-scale field study outlines a cost effective option of implementing improved nutrient management in large tracts of small-scale farming systems in Asia.

Soil test-based fertility management is an effective tool for increasing productivity of agricultural soils that have a high degree of spatial variability. However, major constraints impede wide scale adoption of soil testing in most developing countries. In India, these include the prevalence of small holding systems of farming as well as lack of infrastructural facilities for extensive soil testing (Sen et al., 2008). Under this context, GIS-based soil fertility mapping has appeared as a promising alternative. Use of such maps as a decision support tool for nutrient management will not only be helpful for adopting a rational approach compared to farmer practices or blanket use of state recommended fertilisation, but will also reduce the necessity for elaborate plot-by-plot soil testing activities. However, information pertaining to such use of GIS-based fertility maps has been meager in India (Sen and Majumdar, 2006; Sen et al., 2008). The current study was initiated to assess the relative efficiency of GIS map-based soil fertility evaluation with regard to traditional soil testing in the red and lateritic soil zone of West Bengal.


GIS-based fertilizer recommendations focused farmers on nutrient management for their entire rice-potato-sesame crop rotation.

This on-farm study was conducted during 2007/08 at Meherpur Village of Birbhum District in the lateritic soil zone of West Bengal. The village represents 543 land holdings within a 76-ha area. The area falls under the hot, dry sub-humid zone, 60 m above mean sea level, with year round temperatures between 6.6 to 41.4 °C and a relative humidity range between 47.7 to 96%. Average annual rainfall is about 1,192 mm, mainly concentrated between June and September. Soils from this area are generally mixed Hyperthermic Typic Haplustalfs with sandy loam texture, moderate water holding capacity, acidic pH, and low fertility status. The crop system under study was a monsoon rice-potato-sesame cropping system.

Geo-referenced soil samples were collected on a 50-m grid and were analysed for common soil productivity attributes including pH, organic C, available N, P, and K by standard methods (Jackson, 1973). The data were then integrated into a GIS platform (ESRI, 2001). An inverse distance-weighted method of interpolation created continuous surface maps for each parameter, allowing estimation of soil properties for unsampled points within the study area (Sen et al., 2008). See **Figure 1**. The spatial variability for each attribute was assessed using spatial descriptive statistics (Iqbal et al., 2005). A comparative assessment of soil pH and nutrient content values obtained from random sampling (10 samples from an area of about 20 ha) versus those predicted from the GIS found only minor variations in available N content. There was practically no variation in available P content under the two methods of evaluation **(Table 1)**. A larger difference was observed in the case of available K. Red and lateritic soils typically have low available N and P status, but soil K was well distributed between low, medium, and high fertility groups and was not well predicted through the GIS interpolation.

Abbreviations: C = carbon; N = nitrogen; P = phosphorus; K = potassium; CD = critical difference, equivalent to Least Significant Difference; INR = Indian rupee (USD 1 is equal to approximately INR 46).

Table 1. Comparison of samples (%) that fall under low, medium, and high nutrient availability and pH categories under two systems of assessment.

	Low/Acidic		Medium/Neutral		High/Alkaline	
Parameter	Soil test	GIS	Soil test	GIS	Soil test	GIS
Available N	89	78	11	22	0	0
Available P	100	100	0	0	0	0
Available K	44	33	33	67	22	0
pH	56	67	44	33	0	0

Table 2. Nutrient rates (kg N-P_2O_5-K_2O/ha) used in each treatment and crop.

Treatments	Rice	Potato	Sesame
Farm	60-30-30	300-200-200	Residual
State	80-40-40	200-150-150	80-40-40
Soil test	Variable	Variable	Variable
GIS	Variable	Variable	Variable

The relative effectiveness of recommendations generated through the grid-based, village-level GIS was evaluated against results obtained from common farmer practice, blanket fertiliser recommendations generated from the State, and field-specific, soil test-based recommendations within a monsoon rice-potato-sesame cropping system **(Table 2)**. Average yields for the initial rice crop were significantly higher under soil test and GIS-based soil fertiliser application over farmer practice

Table 3. Yield of rice, potato, and sesame under different crop fertilisation strategies.

	Rice				Potato			Sesame			
	Yield, t/ha		Economics[1], INR		Yield, t/ha	Economics, INR		Yield, t/ha		Economics, INR	
Treatment	Grain	Straw	Net return	Return per INR invested	Tuber	Net return	Return per INR invested	Seed	Stick	Net return	Return per INR invested
Farm	4.2	4.6	20,592	1.90	28.7	38,210	1.50	0.8	3.0	3,928	1.22
State	4.4	5.0	21,544	1.91	22.5	20,962	1.30	1.2	3.9	8,278	1.51
Soil test	4.7	6.0	25,614	2.05	28.3	41,556	1.58	1.4	4.2	11,267	1.66
GIS (100-m grid)	4.7	6.0	24,760	2.02	27.6	39,128	1.55	1.4	4.1	11,457	1.68
CD at 5%	0.26	0.32	-	-	6.4	-	-	0.3	0.4	-	-

[1] Economic comparisons considered all fixed and variable costs including fertilisers (urea = INR 6/kg, SSP = INR 6/kg, KCl = INR 6/kg) and revenues from rice grain (INR 9/kg) and straw (INR 1.2/kg), potato tubers (INR 4/kg), and sesame seed (INR 20/kg) and sticks (INR 100/t).

and State recommended fertilisation **(Table 3)**. Yield levels under soil test-based and GIS map-based fertilisation were statistically at par, indicating feasibility for using GIS-based fertility maps for nutrient management. The following potato crop had equivalent tuber yields across treatments, which can be attributed to the tendency for farmers to use relatively high rates of fertiliser in potato. In sesame, yields were generally low due to a scarcity of irrigation water during the season. However, yields of sesame did follow a similar trend to that observed in rice. Thus, fertiliser recommendations generated from GIS maps were agronomically as effective as those generated from soil testing. Comparatively, the GIS and soil test-based fertiliser application was higher than State recommendation and farmer practice in rice and sesame. However, potato farmers applied higher amounts of nutrient than State recommendation as well as soil test or GIS-based fertiliser application. A complete economic assessment suggests net returns were maximised under field-specific recommendations in rice and potato, followed by GIS interpolation. In sesame, the GIS-based recommendations were marginally better than those obtained by field sampling. An additional consideration involves the cost of implementing new sampling strategies at the village-scale. Successful adoption of such technologies could rest on proposing a lowest cost solution which, in this setting, is advantageous to grid sampling through its lower sampling density **(Table 4)**.

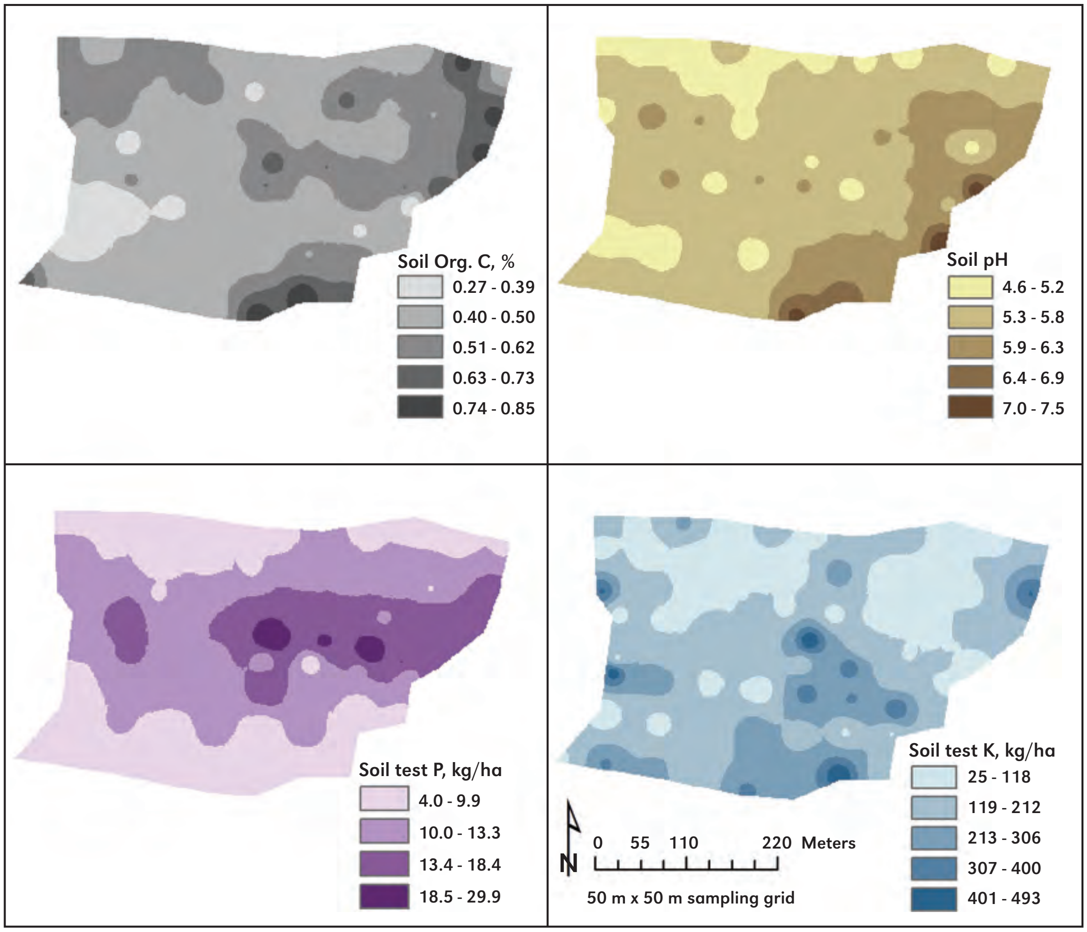

Figure 1. Maps show soil organic C, soil pH, soil test P, and soil test K for study at Meherpur Village.

It is likely that variation between estimates of nutrient availability under the two preferred systems was minimised when values were categorised and recommendations were generated. To substantiate this, a comparison was made between the mean fertiliser (NPK) doses under the soil test and GIS-based treatments for each crop. Results found the N and P application rates to be equal, but K rates varied slightly (data not shown), which again was attributed to comparatively higher variation in the availability of soil K.

Researchers also conducted another study simultaneously to assess the effect of grid size on map development and the predictability of soil fertility status. A substantial amount of research has tried to assess the appropriate sampling density needed to characterise the central tendency of soil properties with a specified degree of accuracy (McBratney and Webster, 1983; Webster and Oliver, 1990). A larger number of samples can produce more accurate maps (Mueller et al., 2001; Wollenhaupt et al., 1994); however, the cost of sample collection and analysis can be prohibitive. Previous research suggests

Table 4. Outline of implementation cost associated with improved village-scale sampling strategies.

Total number of land holdings		543
Total cultivated area of the village in hectares		76 ha
Actual cost of field-based soil testing (NPK analysis, commercial lab)		543 x INR 50 = INR 27,150
Actual cost of soil testing for GIS	50-m x 50-m sampling	304 x INR 50 = INR 15,200
	100-m x 100-m sampling	76 x INR 50 = INR 3,800
	250-m x 250-m sampling	19 x INR 50 = INR 950

Table 5. Yields (t/ha) of rice, potato, and sesame under different crop fertilisation strategies and grid sizes.

	- - - - Rice - - - -		- Potato -	- - - Sesame - - -	
Treatment	Grain	Straw	Tuber	Seed	Stick
Farm	4.0	4.2	27.7	0.8	2.7
State	4.3	4.8	21.9	1.2	3.9
GIS (50-m grid)	4.5	5.8	27.2	1.4	4.1
GIS (100-m grid)	4.4	5.6	27.1	1.4	4.1
GIS (250-m grid)	4.3	5.3	25.5	1.4	3.9
Soil test	4.6	5.9	27.3	1.4	4.2
CD at 5%	0.3	0.5	1.6	0.2	0.3

that soil sampling on 60-m grids (Hammond, 1992) or even 30-m grids (Franzen and Peck, 1993) might be needed, but most commercial soil sampling is done on a 100-m grid basis.

To arrive at a cost effective grid size of sampling, researchers compared actual soil analysis values of pH, organic C and available P and K contents of random samples from the study area with values predicted from GIS maps using 50, 100, and 250-m grids. Predicted soil fertility levels were classified into low, medium, or high categories according to existing norms (Ali, 2005). Variation existed for soil parameters values under the three grid sizes, but the deviations from the actual soil test values were insignificant and made no difference when the values were classified into high, medium and low categories (data not shown).

Collecting soil samples within the fragmented landscape of the village of Meherpur, West Bengal.

Trials on the rice-potato-sesame cropping system were carried out using fertiliser recommendations predicted from these different grids, which were also evaluated against farmer practice, State recommendations, and field-specific, soil test-based recommendations. Higher rice grain and straw yields were obtained with either GIS or soil test-based fertilisation compared to farmer practice **(Table 5)**. However, unlike the three GIS sampling grids, field-specific soil testing did generate superior rice grain yields over the State's blanket recommendation. No significant difference in rice yield was found among the three grid-based recommendations, although yields gradually declined with increasing grid size, to the point where yields obtained under the 250-m grid were significantly less than those obtained with soil test-based fertilisation. For potato, farmer practice was once again a relatively high yielding treatment while the State recommendation provided the lowest yield overall. The 50-m and 100-m grid-based maps also provided comparatively better results than the 250-m map, such that these grid sizes generated tuber yields that were comparable to soil test-based fertilisation. In sesame, farmer practice resulted in the lowest yield among all the treatments. Traditional practice in sesame largely relies on residual soil fertility after potato. The blanket State recommendation had higher seed and stick yields over farmer practice. However, considerably higher yields were obtained under the soil test-based and three grid-based recommendations. No significant differences in sesame seed yield were observed between soil test- and GIS-based fertilisation as well as between the three grid sizes.

In contrast to developed countries, where precision nutrient management addresses in-field nutrient variability in large-scale individual operations, this study's approach addresses spatial variability of soil parameters between fields at the village scale. Geostatistical analysis and GIS-based mapping provided an opportunity to assess variability in the distribution of native nutrients and other yield limiting/building soil parameters across a large area. This has helped to increase awareness at the village scale, while helping farmers strategise for appropriate management of nutrients and strive for better productivity throughout their entire crop sequence.

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Long-Term Effects of Integrated Nutrient Management on Planted and Successive Ratoon Sugarcane Crops

By S.M. Bokhtiar, G.C. Paul, K.M. Alam, M.A. Haque, and M.S. Arefin

Improving soil organic matter and soil fertility are important factors in sustaining sugarcane production. This long-term experiment evaluated the effect of organic amendment, green manuring, and fertiliser combinations on yield and soil fertility status within a multi-ratooning cane cropping system. Over the 7-year period, high yields were sustained, and soil organic carbon, total N, available P, and exchangeable K were increased with long-term, annual applications of press mud and/or farmyard manure (FYM) plus fertilisers compared to fertiliser application alone.

The possibility of increasing the area under sugarcane in Bangladesh (presently 150,000 ha) remains meager due to a continued, heavy demand for cereals destined for staple food production. Thus, the primary option available to meet the requirement for sugar and jaggery is through an increase in the productivity per unit area, and ratoon cane fields represent such an opportunity. In sugarcane production, ratoon cropping is an established practice contributing significantly to overall profitability. Ratoon crops are 25 to 30% cheaper to grow than planted cane fields (Sundara, 1987), since no cost is involved for fresh seed material and land preparation, and there is a savings in irrigation and crop maintenance through reduced crop duration.

In many sugarcane growing countries of the world, raising several successive ratoons is common, with the number of ratoons ranging from 1 to 20 (Hunsigi, 1989). Despite this, multi-ratooning is seldom practiced in Bangladesh due to significant yield declines over time. One of the major causes for this cane yield reduction is the decline in soil nutrient status (Plucknett et al. 1970; Soopramanien and Hunsigi 1995). In Bangladesh, most of the cultivated land contains less than 2% organic matter and the soils of high and medium-high lands have organic matter contents less than 1% (FRG, 2005). It is understood that declining productivity of Bangladesh soils is the result of depletion of organic matter due to increasing cropping intensity, higher rates of decomposition of organic matter under the prevailing hot and humid climate, and limited or no use of organic matter or green manures. The country is in great need of nutrient replenishment strategies that integrate the addition of organic matter with fertiliser for higher yields in both planted and ratoon crops.

The Bangladesh Sugarcane Research Institute (BSRI) farm at Ishurdi, Pabna (24° 8' N latitude and 92°5' E longitude), located on the High Ganges River floodplain, was selected for the study conducted between 2001-02 and 2007-08. Composite soil samples (0 to 15 cm) were collected randomly from each replicated plot before fertiliser application. The soil was a calcareous silt loam (Typic Eutrochrepts) with a pH near 8.0, low organic matter (1.14%), and very low in total N, available P, and S...0.06%, 8.0 mg/kg, and 6.0 mg/kg, respectively. Exchangeable K (0.19 cmol/kg) and soil cation exchange capacity (14.0 cmol/kg) of the experimental soil were also low.

Treatments tested various nutrient management options including: T_0 = Control (no fertiliser); T_1 = NPKS and Zn based on soil test results and an optimum yield target of 100 ± 10 t/ha; T_2 = T_1+ farmyard manure (FYM); T_3 = 25% less fertiliser than T_1 + FYM; T_4 = T_1+ press mud; T_5 = 25% less fertiliser than T_1 + press mud; T_6 = T_1+ green manure (*Crotalaria juncea*); T_7 = Current recommended rates; and T_8 = 25% more fertiliser than T_7 **(Table 1)**. Treatments were replicated four times and experimental plots were set up in a randomised complete block design. Urea, triple superphosphate (TSP), potassium chloride

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; S = sulphur; Ca = calcium; Mg = magnesium; Mn = manganese; Cu = copper; Fe = iron; Zn = zinc.

Table 1. A description of treatments used in the study.

Treatment	- - - - - - - - - Fertiliser, kg/ha N^2	P	K	S	Zn - - - - - - - - -	Organic amendments, t/ha PM	FYM	Green manure
T_0 = Control (no fertiliser)	0	0	0	0	0	0	0	0
T_1 = Soil test-based NPKS and Zn[1]	178	53	54	26	2.6	0	0	0
T_2 = T_1+ FYM	178	53	54	26	2.6	0	15	0
T_3: = 75% T_1 + FYM	138	40	40	20	2.0	0	15	0
T_4 = T_1+ PM	178	53	54	26	2.6	15	0	0
T_5 = 75% T_1 + PM	138	40	40	20	2.0	15	0	0
T_6 = T_1+ GM	178	53	54	26	2.6	0	0	GM
T_7 = Current recommendation	130	35	60	20	3	0	0	0
T_8 = 125% Current recommendation	163	45	75	25	4	0	0	0

[1] Based on target yield of 100 t/ha ± 10 t/ha.

[2] N rates indicated were applied in the planted crop. Successive ratoon crops received 50% more N than the planted crop.

Table 2. Composition of press mud, FYM, and green manure (oven-dry basis).

Amendment	Moisture, %	pH	OC	Total N	P	K	S	Ca	Mg	Cu	Fe	Mn	Zn
			- - - - - -	- - - - - -	- - - - - -	%	- - - - - -	- - - - - -	- - - - - -	- - - - - -	mg/kg	- - - - - -	- - - - - -
Press mud	55.95	5.8	19.5	2.01	0.13	0.54	0.56	6.64	0.46	128	6,300	308	883
FYM	45.83	7.1	14.0	1.21	0.08	0.41	0.22	2.98	0.94	84	6,490	200	546
G. manure	76.03	-	45.9	1.79	0.18	1.44	0.17	-	-	-	-	-	-

Table 3. Effects of integrated nutrient management practices on yield (t/ha) of the planted and successive ratoon cane crops at Ishurdi, Pabna, Bangladesh.

Treatments	Planted cane	First ratoon	Second ratoon	Third ratoon	Fourth ratoon	Fifth ratoon	Sixth ratoon
T_0	50.82 e	35.26 d	26.35c	22.26 d	13.07 e	14.34 c	8.49 e
T_1	91.24 cd	78.94 c	61.25b	64.41 abc	59.58 bc	61.66 ab	37.53 d
T_2	108.40 a	96.82 a	73.54a	71.51 a	62.97 abc	63.78 ab	47.58 b
T_3	105.40 ab	89.96 ab	72.50ab	70.46 ab	64.74 ab	68.88 ab	39.62 cd
T_4	100.50 abc	89.65 ab	72.18ab	65.89 abc	69.63 a	70.37 ab	52.41 a
T_5	100.70 abc	84.97 bc	67.97ab	60.95 abc	69.32 a	72.58 a	43.93 bc
T_6	97.17 bcd	80.46 bc	63.90ab	58.17 c	49.53 d	63.43 ab	37.70 d
T_7	88.60 d	80.81 bc	61.93ab	60.38 bc	56.98 cd	58.87 b	36.79 d
T_8	96.80 bcd	84.24 bc	65.73ab	63.68 abc	55.31 cd	69.57ab	38.69 d
LSD at 0.05	9.91	10.52	11.69	10.84	7.73	12.00	4.55

Means followed by different letters within a column are significantly different ($p < 0.05$).

Table 4. Changes in soil pH, organic carbon and available nutrients as influenced by integrated nutrient management practices after 7 years at Ishurdi, Pabna, Bangladesh.

Treatments	Soil pH	Organic C, %	Total N, %	Available P, mg/kg	Exchangeable K, cmol$_+$/kg
T_0	7.83a	0.74c	0.05c	9.00d	0.16c
T_1	7.79ab	0.74c	0.07b	16.67c	0.17bc
T_2	7.73bcd	0.84bc	0.07b	20.67c	0.20a
T_3	7.74bcd	0.86bc	0.07b	19.67c	0.18ab
T_4	7.79ab	1.02a	0.08ab	47.33a	0.17bc
T_5	7.73cd	1.04a	0.09a	40.00b	0.17bc
T_6	7.79ab	0.86bc	0.08ab	21.33c	0.17bc
T_7	7.71d	0.96ab	0.07b	17.00c	0.17bc
T_8	7.78abc	0.80c	0.07b	11.00d	0.17bc
LSD at 0.05	0.05	0.13	0.02	4.35	0.02

Means followed by different letters within a column are significantly different ($p < 0.05$).

(KCl), gypsum, and zinc sulphate were used as the sources of N, P, K, S, and Zn, respectively.

Sugarcane plants (variety Isd 20) with 3 to 4 leaves were transplanted on December 10, 2001. The plot size was 8 m × 6 m in which six rows of cane were planted within an inter-row spacing of 1 m and 0.45 m interplant spacing. The green manure crop was seeded at 250 g/plot (without fertiliser) during the summer season (mid April) in-between cane rows and then ploughed down in-situ 45 days after sowing. Other farming practices such as supplementary irrigation, weeding, earthing-up, tying, and pest control were done as and when required.

For planted sugarcane, the full amount of press mud, FYM, TSP, gypsum, zinc sulphate, and one-third of the KCl were applied in trenches and thoroughly mixed with soil prior to seedling transplantation and irrigation. The N fertiliser was applied in three equal splits; at establishment of seedlings [i.e. 20 days after planting (DAP)], at tillering completion stage (90 DAP), and at grand growth phase (180 DAP). The remaining two-thirds of KCl was applied as top dressing at 90 DAP and 180 DAP as was N fertiliser. The nutrient composition of press mud collected from the North Bengal Sugar Mills, Bangladesh, well rotten FYM, and green manure is shown in **Table 2**.

The ratoon cane experiment was initiated in 2002-03 and continued up to the sixth ratoon crop in 2007-08. Ratoon cane received 50% more N than the planted crop, but all other fertilisers and amendments were kept at the same levels mentioned above. Ratoon crops require more N because 3 to 6 weeks after sugarcane ratoons start growing from old stubble roots, these old root system cease to function and new root systems are formed. Since these new root systems are surrounded by old, decomposing tissue with high C:N ratio, the potential for microbial immobilisation of available soil N is high in the root zone and higher rates of N application are required to overcome this microbial tie up of nutrients.

Results

Use of organic amendments and fertilization significantly increased the yield of planted cane and successive ratoon crops (**Table 3**). The maximum cane yields were obtained from soil test-based fertilisation plus FYM (T_2) in the planted, first, second, and third ratoon crops. The maximum yields for the fourth to sixth crop were achieved with either of the fertiliser/press mud combinations (T_4 or T_5). But regardless of the rankings, sustained agronomic performance of treatments providing an organic amendment along with soil test-based fertilisation highlights the significance of this practice in multi-ratooned crops. Tiwari et al. (1998) also found increased cane and sugar yield with continuous application of press mud and N fertiliser, as did researchers at TNAU where sugarcane intercropped with green gram and press mud application at 25 t/ha generated similar results (TNAU, 2000). Press mud at 12.5 t/ha + 75% of the recommended NPK rate increased cane yield by 20% over 100% NPK alone (Suguna Devakumari, 2005). In addition to their direct nutrient value, organic amendments (and green manures), when incorporated into the soil, increase biological activity, nutrient availability, soil organic carbon, and physiochemical properties of soil through their biodegradation. Organic amendments are likely to improve the porosity in soil, improve water holding capacity, reduce soil compaction, improve root penetration, and encourage vigorous growth and development of planted and ratoon crops.

Our results also indicate that the application of FYM and/or press mud was more effective than green manure or fertiliser in maintaining ratoon crop yields over time. However, due to additive effects of combining nutrient sources on ratoon crop yields, maximum crop cycle yields were recorded for treatments with a combination of press mud and/or FYM. Our results concur with Gilbert et al. (2008).

Among the different fertiliser management practices, a combined application of press mud and/or FYM and fertiliser generated slight improvements in soil organic carbon, total N, available P, and exchangeable K over the control treatment **(Table 4)**.

Details economic data for the different nutrient management practices provide the basis for marginal benefit: cost ratios (MBCR) presented for planted **(Table 5a)** and ratoon sugarcane **(Table 5b)**. MBCR values varied with yield as well as the associated cost as per treatment description. Importantly, the incorporation of organic manure and fertiliser in these long-term, planted/ratoon cropping systems was profitable. Based on the seven years of experimentation, the following recommendations were drawn.

- A 25% reduction in the current fertilizer recommendation (i.e., 138-40-40-20-2 kg N-P-K-S-Zn/ha) plus either a similar quality FYM or press mud at 15 t/ha may be recommended for higher yields, incomes, and soil fertility maintenance in planted crops.
- Successive ratoon crops perform better under the same recommendation outlined above; however, these crops should be compensated with 50% more N than is applied in planted crops due to the high potential for microbial immobilisation of available soil N.

Table 5a. Economic analysis of sugarcane as affected by different fertilisers management practices for planted cane.

Treatments	Planted cane yield, t/ha	Gross return, BDT/ha	Variable cost[1], BDT/ha	Gross margin, BDT/ha	Marginal benefit to cost ratio (MBCR) over the control
T_0	50.8	89,951	0	89,951	-
T_1	91.2	161,495	15,187	146,308	3.7
T_2	108.4	191,868	24,187	167,681	3.2
T_3	105.4	186,558	20,550	166,008	3.7
T_4	100.5	177,885	18,187	159,698	3.8
T_5	100.7	178,239	14,550	163,689	5.1
T_6	97.2	171,991	15,187	156,804	4.4
T_7	88.6	156,822	12,124	144,698	4.5
T_8	96.8	171,336	15,390	155,946	4.3

[1] Variable cost includes the cost of fertilisers and amendments only. BDT = Taka, a unit of Bangladeshi currency. 1 USD = approximately 69 BDT.
Costs of inputs: urea (12 BDT/kg), triple superphosphate (22 BDT/kg), potassium chloride (25 BDT/kg), gypsum (8 BDT/kg), zinc sulphate (120 BDT/kg), press mud (0.20 BDT/kg), and FYM (0.60 BDT/kg).
Price of output: Sugarcane (1,770 BDT/t).

Table 5b. Marginal benefit to cost ratio over the control as affected by different nutrient management practices for successive ratoon crops.

	Marginal benefit cost ratio (MBCR) over the control[1]					
Treatments	First ratoon	Second ratoon	Third ratoon	Fourth ratoon	Fifth ratoon	Sixth ratoon
T_0	-	-	-	-	-	-
T_1	3.4	2.5	3.1	3.7	3.8	1.9
T_2	3.1	2.2	2.3	2.3	2.3	1.6
T_3	3.3	2.7	2.8	3.1	3.3	1.5
T_4	3.7	3.0	2.8	3.9	4.0	2.8
T_5	4.4	3.5	3.2	5.1	5.3	2.8
T_6	3.6	2.8	2.6	2.7	4.0	2.0
T_7	4.8	3.6	3.9	4.6	4.7	2.6
T_8	4.0	3.0	3.2	3.3	4.6	2.0

[1] To calculate MBCR for ratoon crops, 50% more N cost was considered in the variable costs. All other fertilizers and amendments were kept at the same levels.

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The Current Scenario and Efficient Management of Zinc, Iron, and Manganese Deficiencies

By U.S. Sadana, J.S. Manchanda, M.P.S. Khurana, S.S. Dhaliwal, and Harmanjit Singh

Of the micronutrients, zinc (Zn) deficiency is the most widespread problem in Punjab State. Soil application of zinc sulphate ($ZnSO_4$) is the most commonly used method to correct Zn deficiency in different crops. Severe iron (Fe) and manganese (Mn) deficiency is difficult to manage with soil application due to the oxidation of soil-applied Fe and $MnSO_4$ at high soil pH. Foliar application of Fe and Mn is an immediately effective measure to combat deficiency; however, both have to be applied repeatedly. A separate approach could be sowing of nutrient efficient crops that grow well on soils low in micronutrients. Selection and screening of micronutrient efficient crops should be carried out on a priority basis.

Micronutrient deficiencies have become one of the major constraints in sustaining crop production in the present exploitive agriculture. These deficiencies appeared much faster in the northern states as compared to other parts of the country, which may be attributed primarily to the fast adoption of new agricultural technology, including: cultivation of high yielding crop varieties, increase in cropping intensity, expansion of irrigation facilities, increased use of high analysis fertilisers, and poor quality irrigation water (Nayyar, 1999). Food grain production, no doubt, increased tremendously and made the country self-sufficient in food grains, yet it resulted in the faster depletion of the finite micronutrient reserves of soils. Adoption of the rice-wheat system, particularly in the non-traditional rice growing areas, has resulted in over-exploitation of the natural soil resource base and this trend has been enhanced by the imbalanced use of inputs. The increased use of poor quality irrigation water to meet the water requirement of this cropping system has further aggravated the problems of micronutrient deficiencies.

An early result of such exploitive agriculture practices was the appearance of Zn deficiency in many parts of the country. Field-scale deficiency of Zn was first noticed in rice on Tarai soils (Mollisols) in 1965, then in wheat on sandy soils of Punjab in 1970, and later in most of the intensively cultivated areas, particularly where rice and wheat were grown. Subsequently, deficiencies of Fe and Mn were recorded in particular situations, and their severity depended on soil conditions and the crop grown.

Present Scenario of Micronutrient Deficiencies

The total micronutrient contents of soils are generally of limited value as far as plant growth and responses to their application are concerned. In most cases, total contents are not significantly related to plant content. In order to match the levels of micronutrients in soil with plant requirement, their available contents are determined. Most researchers have used the DTPA soil test method for determining the available content of Zn, Fe, and Mn, particularly in alkaline calcareous soils. Like total contents, the available micronutrient status of soils is also highly variable. Analysis of more than 15,000 soil samples from different districts of Punjab have shown that available Zn, Fe, and Mn content of Punjab soils ranged from 0.02 to 10.4, 0.5 to 176, and 0.8 to 120 mg/kg soil with mean values of 0.95, 10.7, and 11.3 mg/kg soil, respectively (Nayyar et al., 1990).

Abbreviations and notes: ppm = parts per million; FYM = farm yard manure.

Manganese deficiency in wheat.

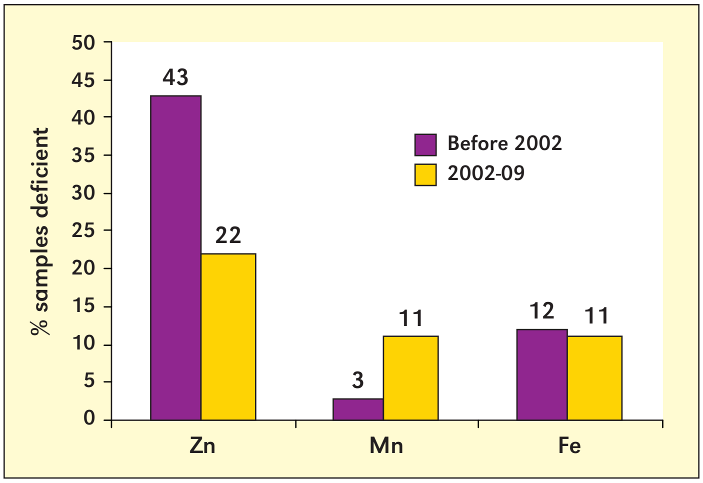

Figure 1. Temporal changes in Zn, Mn, and Fe status of Punjab soils.

Considering 0.6 ppm DTPA-extractable Zn as the critical limit for Zn deficiency, 22% of soils in the State are presently deficient, which has decreased from 43% in 1990 **(Figure 1)**. The soils of the south-western districts of the State are more prone to Zn deficiency compared to central and sub-mountainous districts. Further, soils that are coarse in texture, low in organic matter, and high in pH and $CaCO_3$ are more prone to Zn deficiency. Also, acute Zn deficiency in rice and significant response to Zn application was observed in flood

Zinc deficiency in rice.

Iron deficiency in rice.

plains and sodic soils of the State (Nayyar et al., 1990; Sharma et al., 1982; Sadana and Takkar, 1983).

Iron deficiency is widespread in crops grown on coarse-textured and calcareous soils. In Punjab, Fe is considered to be the second most limiting micronutrient in crop production after Zn. Poor availability of Fe in the soil, insufficient uptake and Fe inactivation within the plants are reported to be the main causes of Fe chlorosis in crops grown on such soils. In view of the high sensitivity of Fe to electro-chemical changes in soils, addition of easily decomposable organic carbon (C) materials is expected to increase the availability of native soil Fe (Sadana and Nayyar 2000). Considering 4.5 ppm DTPA-extractable Fe as the critical limit, about 12% of soils of Punjab are deficient in Fe.

Considering 3.5 ppm DTPA-extractable Mn as the critical limit (Nayyar et al, 1985), Mn deficiency has increased from 2% to 11% over the years. The increase in incidence of Mn deficiency, particularly in wheat and berseem, could be attributed to the previous cultivation of rice on coarse-textured soils, which leads to leaching of Mn to deeper soil layers during the rice season and following wheat or berseem crops show Mn deficiency. Severe Mn deficiency is difficult to manage with soil application due to oxidation of soil-applied Mn at high soil pH. Foliar application of manganese sulphate fertiliser is an immediate effective measure to combat Mn deficiency in wheat and Berseem (Nayyar et al., 1985, 2006; Sadana et al., 1991; Takkar et al, 1986) though it has to be applied every year. Among different crops, raya has been found more Mn efficient than wheat on Mn-deficient soils (Khurana et al., 2008; Sadana et al., 2003; Samal et al., 2003). Durum wheat cultivars are more sensitive to Mn stress and are not recommended on Mn deficient soils (Bansal and Nayyar, 1998; Bansal et al. 1991; Nayyar, 1999; Sadana, 2002, 2005).

Management Practices

Zinc application has increased the average yield by 340 to 950 kg/ha in cereals, 230 to 410 kg/ha in millets, 110 to 330 kg/ha in oilseeds and pulses, and 240 kg/ha in cotton (Nayyar et al. 1990). Response of crops to applied Zn generally increases as soil texture becomes coarser.

By and large, $ZnSO_4$ proves to be the efficient and economical source for correction of Zn deficiency in crops compared to relatively insoluble Zn carriers as well as several multi-micronutrient mixtures. However, organic manures (i.e., 12 t/ha FYM, 5 t/ha poultry manure, and 2.5 t/ha pig manure) were as efficient as 11 kg Zn/ha in meeting the Zn requirements of a maize-wheat rotation (Nayyar et al. 1990). Also half or even smaller quantities of these manures proved equally efficient or better for maize-wheat when amended with half the rate of Zn fertiliser. Among different application methods, soil application of $ZnSO_4$ through broadcast and incorporation proved more efficient compared to placement below or beside the seed, or through top-dressing. Foliar sprays of 0.5 to 1.0% $ZnSO_4$ neutralised solution proved inferior to soil application of Zn to wheat and rice. All other methods such as coating or soaking of seeds in Zn solutions, dipping rice seedling roots in ZnO suspension, and transplanting Zn-enriched nursery stock proved either inferior or just at par with soil application of Zn in combating its deficiency in crops.

The optimum rates of Zn application for different crops have been evaluated and recommendations devised. Soil application of zinc sulphate hepta hydrate (21% Zn) at 62.5 kg/ha or of zinc sulphate mono hydrate (33% Zn) at 40 kg/ha have been found to be equally efficient and economical for correcting Zn deficiency. The best time of Zn application for wheat and rice was found to be at seeding or transplanting of the crops. For the rice-wheat grown on moderately alkali as well as on highly deteriorated sodic soils, both gypsum and Zn proved essential for obtaining the best yields of rice and wheat. In a sandy loam soil, the residual effect of Zn has been found to

Response of wheat (left) to spray application of Mn.

Future Strategies of Research

Screening and/or breeding of micronutrient efficient crops and their cultivars should be done on a priority basis, and more importantly, nutrient efficient crop rotations should be recommended to farmers of the State, particularly those on deficient soils.

Systematic studies to monitor micronutrient deficiencies in different crop rotations and soils should be carried out using GIS. The entire state may be covered once in 2 to 3 years and a repeat survey should be done after 4 to 5 years to monitor the trends. In addition, critical limits for main crops of the State should be refined for different soils.

Limited information is available on emerging deficiencies of B and Cu in the State and on the response of different crops to application of Cu and B in deficient soils. More field experiments should be initiated to generate information on response, critical limits and their efficient management under field conditions.

Table 1. Benefit:cost (B:C) ratio of micronutrient fertiliser application to crops grown on deficient soils.

Crop	Micronutrient	Details	Average response, kg/ha	Benefit: Cost ratio
Wheat	Mn	3 sprays of 0.5% solution	700	14:1
Rice	Zn	62.5 kg zinc sulphate/ha	950	7:1
Wheat	Zn	Residual effect after rice	360	
Rice	Fe	3 sprays of 1% solution	1,880	5.4: 1

persist for 2 years in wheat-rice, gram-bajra, potato-guara, and wheat-maize rotations.

Iron deficiency is acute in rice grown on coarse-textured soils newly brought into cultivation. Rice grown on coarse-textured, alkaline soils can give striking responses to Fe application. Depending upon soil conditions, responses range from 200 to 7,300 kg/ha. Soil application of ferrous sulphate (19% Fe) proved noticeably inferior to three sprays of 1% ferrous sulphate solution in mending Fe deficiency in rice grown on sandy soils. Green manuring in rice markedly decreases the severity of Fe chlorosis in rice.

Significant responses of wheat grown in rotation with rice on alkaline, coarse-textured soils to foliar (0.5 to 1.0 % solution of $MnSO_4 \cdot H_2O$) and soil (25 to 75 kg Mn/ha) application have been observed. Responses range from 200 to 2,950 kg/ha. For correcting Mn deficiency in wheat, $MnSO_4 \cdot H_2O$ (30.5% Mn) proved more efficient than Mn-frits, MnO_2, and other multi-micronutrient mixtures. Three to four foliar sprays of 0.5% $MnSO_4 \cdot H_2O$ solution initiated before the first irrigation proved more effective and economical compared to soil application of Mn. It commonly requires 7.5 to 10 kg $MnSO_4 \cdot H_2O$/ha to fully ameliorate Mn deficiency.

Economic benefits of application of different micronutrients fertilisers to crops grown on deficient soils is given in **Table 1**.

Summary

For efficient management of Zn deficiency in different crops, soil application of zinc sulphate hepta hydrate (21% Zn) at 62.5 kg/ha or of zinc sulphate mono hydrate (33% Zn) at 40 kg/ha have been found to be equally efficient and economical for correcting Zn deficiency. Iron deficiency is acute in rice grown on coarse-textured soils newly brought under cultivation. Soil application of ferrous sulphate (19% Fe) proves to be inferior to 3 sprays of 1% ferrous sulphate solution in mending Fe deficiency in rice grown on sandy soils. Green manuring in rice can markedly decrease the severity of Fe chlorosis in rice. For correcting Mn deficiency in wheat, 3 to 4 foliar sprays of 0.5% $MnSO_4 \cdot H_2O$ solution initiated before the first irrigation proves to be more effective and economical as compared to soil application of Mn.

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A Review of Crop Productivity and Soil Fertility as Related to Nutrient Management in the Indo-Gangetic Plains of India

By Harmandeep Singh and S.K. Bansal

The Indo-Gangetic Plain (IGP) is among the most extensive fluvial plains of the world and covers several states in northern, central, and eastern India. The IGP produces about 50% of the country's foodgrains ...enough to feed 40% of the population of India. The production of grains is, however, not uniform across the IGP regions because of various inadequacies in crop management of which rampant imbalanced fertiliser application is a key influence for stagnating or declining yields, nutrient use efficiencies, and soil health.

The IGP represents eight agro-ecological regions and 14 agro-ecological subregions in the northern, central, and eastern parts of India **(Figure 1)**. It covers about 43.7 million (M) ha, or approximately 13% of the total geographic area of India. Over the last 3 to 4 decades, states within the IGP have been successful in increasing their foodgrain production, chiefly rice and wheat. The strategies and measures that were adopted to achieve this success included the spread of high-yielding varieties, expansion of irrigated area, increased use of fertilisers and plant protection chemicals, strengthening of marketing infrastructure, and the introduction of subsidies. However, the production of grains is not uniform across the IGP region because of the spatial variation in the land resource and socio-economy. In reality, these management interventions intended for a 'money economy' combined with rampant, imbalanced fertiliser application have resulted in widespread cases of degradation and depletion of natural resources, loss of soil carbon, declining water levels, drainage congestion, loss in soil fertility, and nutrient imbalance, including multi-nutrient deficiencies (Abrol and Gupta, 1998; Bhandari et al., 2002). This paper reviews the (i) trends in crop productivity and soil fertility in relation to nutrient management in the IGP, and (ii) available information on the potential of some efficient and site-specific nutrient management (SSNM) strategies to increase crop productivity, boost farm income, and improve overall agricultural sustainability in the IGP.

Figure 1. Indo-Gangetic plains (IGP) of South Asia.

(Adapted from http://www.gecafs.org/research/indo_gangetic.html)

Average vs. Potential Rice-Wheat Yields

In most parts of the IGP where rice-wheat is currently produced, climatic factors allow a potential yield between 12.0 and 19.5 t/ha (Aggarwal et al., 2000). But the average yields of rice and wheat in the states of Punjab, Haryana, Uttar Pradesh, Bihar, and West Bengal are 7.5, 6.1, 4.5, 3.3, and 4.4 t/ha, respectively (Ladha et al., 2003). The large variation in average yields across these different states indicates that, at a regional level, considerable yield gaps still exist in most parts of the IGP. Shukla et al. (2004) observed that in the eastern states of Uttar Pradesh and Bihar, there is a large untapped potential for rice and wheat production. Similarly, Aggarwal et al. (2000) showed that several districts of Uttar Pradesh had potential yields similar to those in Punjab and Haryana. Yet, in most cases farmers of this region were not able to attain higher yields, mainly because of the sub-optimal input use and degrading soil quality.

Abbreviations: N = nitrogen; P = phosphorus; K = potassium; Zn = zinc; B = boron; INR = Indian rupee currency code; M t = million metric tons.

Table 1. Decadal trends in partial factor productivity.

Period	Increase in fertiliser nutrient consumption, M t	Increase in food grain production, M t	Response ratio, kg grain/kg applied nutrients ($N+P_2O_5+K_2O$)
1960-1970	1.47	26.40	17.9
1971-1980	2.44	31.09	12.7
1981-1990	5.28	46.80	8.9
1991-2000	3.18	19.53	6.3

Source: J.K. Ladha, personal communication.

Trends in Productivity

Partial Factor Productivity (PFP) is the average productivity, measured by grain output divided by a single input like fertiliser (Snyder and Bruulsema, 2007). Studies have shown sharply declining trends in the PFP of fertiliser over time in the rice-wheat cropping system of the IGP **(Table 1)**. Although this decline has been cited as a cause for concern about sustainability of the system, PFP can be highly misleading in this context. For example, survey data for a group of farmers in Central Luzon in the Philippines show that it took 10 to 15 years after the introduction of modern varieties for average N use in the wet season to increase from 10 to 60 kg/ha (Ladha et al., 2000). And the spread of higher levels of fertiliser use from one area to another has also taken time, requiring the transmission of knowledge and the construction of irrigation systems. As PFP is negatively correlated with fertiliser use by definition, an increase in fertiliser use will decrease PFP. However, this decline does not always imply a lack of sustainability in the system. Rather, as is clear from the above example, the

Table 2. Nutrient deficiencies observed at different research stations in the IGP under rice-wheat cropping system.

Centers	Nutrients deficient							
	P	K	S	Zn	Fe	Mn	Cu	B
PDCSR, Modipuram	-	√	√	√	-	√	√	√
GBPUA&T, Pantnagar	√	√	-	√	-	√	-	√
CSAUA&T, Kanpur	√	√	√	√	-	-	-	-
NDUA&T, Faisabad	√	√	√	√	-	√	-	√
BHU, Varanasi	√	√	√	√	-	√	√	√
RAU, Sabour	√	√	√	-	-	-	-	-
BAU, Ranchi	√	√	√	√	-	-	-	√
HPKV, Palampur	√	√	√	√	-	-	-	√
PAU, Ludhiana	√	√	√	√	√	√	√	√
R S Pura	√	√	√	√	-	√	√	-

decline was the result of the adjustments farmers had to make to switch to modern varieties.

As an alternative to PFP, it is preferable to calculate sustainability trends through production functions or through Total Factor Productivity (TFP), measured by grain output divided by all inputs (Ali and Byerlee, 2000). Data used to measure TFP at the farm level are difficult to collect because they require a large amount of detail, including the prices and quantities of all inputs and outputs. Nevertheless, Murgai (2000) estimated the trend in TFP in the rice-wheat system of Punjab, and suggested that “fears about unchecked reductions in productivity growth in this system are exaggerated.” However, it is important to remember that TFP does not directly measure environmental degradation. In fact, Ali and Byerlee (2000) found substantial deterioration of soil and water quality in all cropping systems in Pakistan’s Punjab, including those with positive TFP growth. It was most severe in the wheat-rice system, where it reduced TFP growth by 0.44% per annum during the period 1971-94. If TFP growth is positive in the presence of environmental degradation, this indicates that technological progress and improved infrastructure have more than compensated for any environmental degradation. But even if this effect has happened in the past there is no guarantee that it will continue in the future.

Trends in Soil Fertility

Research conducted in the IGP over the last 20 years indicates gradual but continuous nutrient mining from soils **(Table 2)**. First, there has been a widening N:P:K use ratio for fertiliser in the IGP. In fact, in a long-term study funded by IPNI (personal communication, unpublished data), N:P:K ratios within the same district varied between 1.6:1.0:1.0 and 3.5:1.7:1.0 within a span of just 8 years (1997-98 to 2004-05). Secondly, the decreased use of organic manures, reduced recycling of crop residues, and bumper harvests over the past three decades have induced large secondary and micronutrient deficiencies. A survey of Indian soils has revealed that about 49% of soils distributed over 20 states are deficient in available Zn (Nayyar et al., 2001). In the same study, the incidence of B deficiency was found to be the highest in the acid soils of West Bengal followed by the calcareous soils of Bihar.

Impact of Site-Specific Nutrient Management Approaches

In the soil-test based approach to calculate site-specific fertiliser recommendations, fertiliser rates are established based on the concept of crop removal, with an adjustment for soil residual nutrients. While this approach actually fits most production systems in India quite well, given that most of the crop biomass is removed from harvested fields, the role that residual soil nutrients play in meeting crop nutrient requirements becomes a challenge. For example, if a soil tests medium or low in most plant nutrients, then application of these nutrients based on crop removal from a target yield is going to address these nutrient demands. However, on soils where the soil nutrient analysis indicates a high level of nutrient supply, the issue of whether to apply the nutrient at removal rates becomes a challenge to the researcher. The best option, therefore, is to apply all macronutrients and secondary nutrients that are required to meet crop yield removal and those micronutrients that soil testing show to be marginal or deficient. This then provides the environment for full yield expression in the absence of any nutrient deficiency. And once this yield potential of a site has been determined, the next step is to refine nutrient application rates with further field trials. The positive impact of this approach to fertilisation was clearly shown in a series of research experiments conducted by IPNI on soil test-based SSNM in rice-rice and rice-wheat cropping systems in seven different locations in the IGP. When the yield-limiting nutrients were identified and applied at each location as a SSNM treatment, it was able to generate large improvements in yield and profitability over farm practice across all sites. A smaller gap existed between SSNM and the State recommendation, although most sites still suggested an economic advantage for the SSNM approach **(Table 3)**.

Plant-based SSNM is a dynamic, farm-specific management of nutrients in a particular crop or cropping system using crop-based estimates of indigenous nutrient supply. This approach tries to optimise the supply and demand of nutrients according to their differences in cycling through soil-plant systems. The approach was evaluated comprehensively for agronomic, economic, and environmental performance in 56 farmer fields with irrigated wheat and transplanted rice in Pun-

Table 3. Effect of site-specific nutrient management (SSNM) on wheat productivity (t/ha) and economic return (INR/ha) in parentheses at seven locations in India.

Site	Farm practice	State recommendation	SSNM	Increase over SR, % (INR/ha)	Increase over FP, % (INR/ha)
Ranchi	2.56 (1,575)	4.15 (25,276)	4.06 (26,854)	-2.2 (1,578)	58.5 (25,309)
Modipuram	4.77 (29,292)	4.90 (31,859)	6.43 (58,083)	31.0 (26,224)	46.5 (28,791)
Kanpur	4.72 (7,258)	5.45 (17,644)	6.00 (31,338)	10.1 (13,694)	27.1 (24,080)
Ludhiana	5.45 (27,772)	6.28 (39,105)	6.55 (46,219)	4.3 (7,114)	20.1 (18,447)
Sabour	3.92 (18,306)	4.97 (28,614)	5.82 (45,116)	17.1 (16,502)	48.7 (26,810)
Pantnagar	3.87 (7,828)	5.10 (14,276)	6.39 (19,426)	25.3 (5,150)	66.0 (11,598)
Palampur	2.64 (55,122)	3.76 (54,583)	3.87 (60,905)	3.0 (6,322)	46.5 (5,783)

Table 4. Grain yield of rice and wheat, agronomic (AEN), recovery (REN), and physiological (PEN) N efficiencies, total fertiliser cost (TFC), and gross returns above fertiliser cost (GRF) in 56 farmer fields under rice-wheat cropping system in Punjab.

	----- Rice -----		----- Wheat -----	
	FFP	SSNM	FFP	SSNM
Grain yield, kg/ha	5.1	6	4.2	4.7
AEN,kg grain/kg N	8.8	16.1	8.3	13.6
REN, kg N/100 kg N	20	30	17	27
PEN, kg grain/kg N	34.7	44.2	29.4	37.1
TFC (INR/10 ha)	23,055	34,930	31,059	34,800
GRF (INR/ha)	24,578	28,014	22,316	25,274

jab (Khurana et al., 2007; Khurana et al., 2008). The results of the study clearly brought out the positive impact of SSNM on grain yields, and agronomic, recovery, and physiological efficiencies of N under rice-wheat cropping system in Punjab vis-à-vis farmer practice **(Table 4)**. Also, the highly negative P and K balances observed in farmer fields were reduced using the SSNM approach, indicating that SSNM promotes more balanced fertilisation than is followed by farmers.

A geographical information system (GIS) approach has recently been successfully applied to rice fields (Sen et al., 2008), where developed maps showing the spatial variability in soil nutrient status (Sen et al., 2007) are used as a site-specific fertiliser recommendation tool. This mapping is based on two factors: 1) nutrient content of agricultural soils varies spatially due to variation in genesis, topography, cropping history, fertilisation history, and resource availability; and 2) a lack of adequate infrastructure for soil testing within the patchwork of small holdings. The interpolation technique used in the GIS platform creates a smooth surface map of the study area utilising point information (geographic location and corresponding soil parameters), where each point on the map has a soil parameter value associated with it **(Figure 2)**. Besides the logistical and economic advantages of implementing such a system, once established the technique can create an effective extension tool where field agents work more directly with farmers. Thus, farmers become more aware of how their fields rank within the landscape in terms of basic soil fertility, which in turn enables a system of more rational use of fertiliser application.

Though SSNM approaches are far from perfect, they do help to overcome many of the challenges associated with statewide blanket recommendations that currently are used extensively in the IGP. A systems approach with well-developed analytical framework, databases, and powerful simulation models can improve these approaches further to help sustain food security of India for a long time.

Conclusions

Crop productivity, factor productivity, and soil fertility are not uniform across the IGP regions because of the spatial variation in land-resource characteristics and socio-economy in the region. Also, the imbalanced fertiliser application in the IGP has resulted in stagnating or declining effects on yields, nutrient use efficiencies, and soil health. Nutrient management using new and more efficient, knowledge-intensive, and site-specific approaches have shown promise to help sustain food security of India for a long time. A systems approach with well-developed analytical frameworks, databases, and powerful simulation models can help improve these approaches further. BC-SA

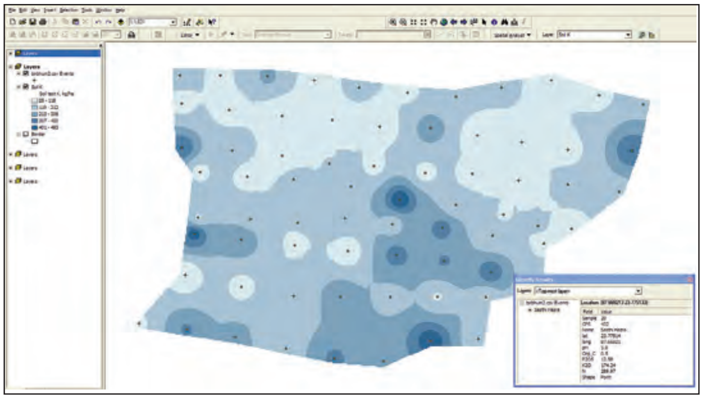

Figure 2. Example of nutrient variability map as a fertiliser decision support tool in farmer fields.

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IPNI Crop Nutrient Deficiency Photo Contest – 2011

Our annual photo contest closes every December and the process of selecting the best submissions begins soon after with winners announced in mid January. The International Plant Nutrition Institute (IPNI) would first like to thank all past contestants and secondly would like to announce plans to continue sponsorship of a photo contest during 2011. The South Asian Region continues to be a strong contributor to the contest and a source of many great examples of documented nutrient deficiencies in crops.

IPNI plans to follow the same contest structure, with four categories in the competition: Nitrogen (N), Phosphorus (P), Potassium (K), and Other. Entries are limited to one per category (one individual could have an entry in each of four categories). Cash prize awards are offered in each of the four categories as follows: • First place = USD 150 • Second place = USD 75 • and a Grand Prize of USD 200 will be offered for the best overall photo entry.

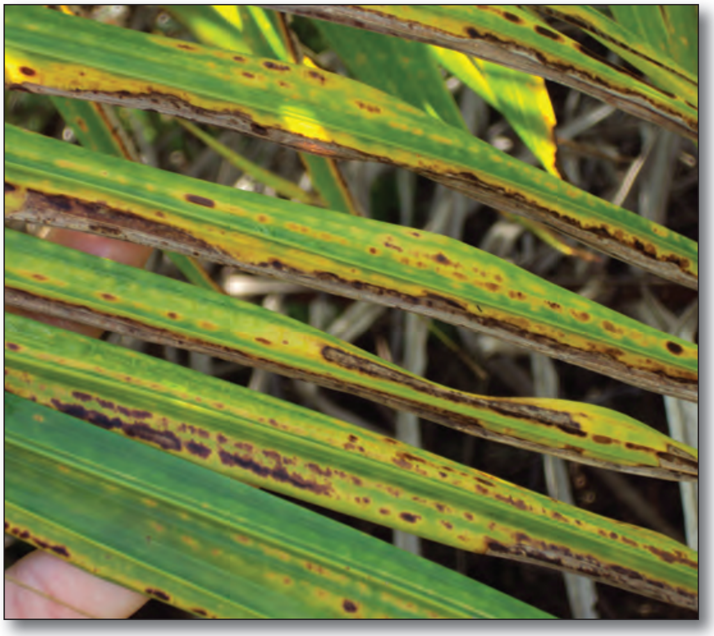
Some specific supporting information is required for all entries, including:

- The entrant's name, affiliation, and contact information.
- The crop and growth stage, location, and date of the photo.
- Supporting and verification information related to plant tissue analysis, soil test, management factors, and additional details that may be related to the deficiency.

As in 2010, photo submissions for 2011 are possible until December 15. Winners will be personally notified and results will be posted on our website.

Entries can only be submitted electronically as high resolution digital files to the organization's website. Please see >www.ipni.net/photocontest< for all the latest details.

For questions or additional information, please contact: Gavin Sulewski, Agronomic and Technical Support Specialist, e-mail: gsulewski@ipni.net BC-SA



Research Supported by IPNI South Asia Programme

The engine that drives the educational programs of IPNI is scientific research support. Here is a listing of the current research being funded in the South Asia region. More details on these projects can be obtained from South Asia Programme staff or from the research database on the website: http://www.ipni.net/research.

South Asia

Cereal Systems Initiative in South Asia

North & East India and Bangladesh

Global Maize Project in India: Ranchi, Jharkhand

Site-Specific Nutrient Management (SSNM) for Rice-Maize Cropping Systems in Bangladesh

Importance of Soil Test Based Nutrient Application through Farmers' Participatory Approach in Red and Lateritic Soils of West Bengal

Appraisal of Multi-Nutrient Deficiencies and their Redressal through Site-Specific Nutrient Management

Evaluating Production Systems Approaching Attainable Yields and Profits

Fertility Mapping and Balanced Fertilization for Sustaining Higher Productivity of Wheat in Agra District

GIS-Based Spatial Variability Mapping of Agricultural Holdings for Precision Nutrient Management in Red and Lateritic Soil Zone

Assessment of K-Supplying Capacity from Soil Nutrient Reserves and Dissemination of Nutrient Management Technologies through Nutrient Manager

Site-Specific Nutrient Management for Rice-Wheat System in Punjab

Site-Specific Nutrient Management for Rice-Wheat System in Haryana

Site-Specific Nutrient Management for Rice-Maize System in Eastern India

South India and Sri Lanka

Global Maize Project in India: Dharwad, Karnataka

Site-Specific Nutrient Management (SSNM) for Maximum Economic Yield and Quality of Transgenic Cotton in Northern Karnataka

Site-Specific Nutrient Management for Optimizing Productivity of Rice-Maize Cropping System in Krishna and Godavari Agro-Climatic Zones of Andhra Pradesh

Fertility Mapping through Spatial Variability in Rice Growing Soils of Cuddalore District of Tamil Nadu

Site-Specific Nutrient Management for Chilli in Kalliyoor Panchayat of Kerala

Improving Nutrient Use Efficiency and Profitability in Rainfed Production Systems

Site-Specific Nutrient Management for Rice-Rice and Rice-Maize System in Tamil Nadu

West India

Inventory of Available Potassium Status and Modeling Its Relationships with Potassium Content, Yield, and Quality of Sugarcane for Site-Specific Nutrient Management in Sugarcane-growing Soils of Maharashtra

Development of Soil Fertility Maps as Decision Support Tool for Fertiliser Recommendation in Citrus

IPNI South Asia Programme regions are staffed by Dr. Kaushik Majumdar, Director (North & East India and Bangladesh), Dr. Harmandeep Singh, Deputy Director (West India), and Dr. T. Satyanarayana, Deputy Director (South India and Sri Lanka). BC-SA

BUILDING PARTNERSHIPS FOR A BETTER TOMORROW

With time comes change, and this year we are welcoming you to the fourth issue of BETTER CROPS–SOUTH ASIA. The change this year is in our name. We have decided to call our programme in India, Pakistan, Bangladesh, Sri Lanka, and Nepal the "South Asia Programme" of IPNI. While India is the dominant agricultural economy in this region, we wanted to be inclusive in covering all the areas where we work in this part of the IPNI world.

Food security is without a doubt the number one agricultural issue in South Asia. And it is easy to find a number of people who have waded into the debate on how much we really do need to increase food production globally, ranging from only 50% to a high of 100% increase by 2050. Well, does the number related to the change really matter? I think that all of us working in the agricultural industry know that we have a major job ahead of us over the next 10 to 20 years to meet any of these targeted food production increases. Let us get focused on building partnerships between agencies so that we can bring together those technologies which, when combined, have the potential to address the urgent need of increasing the rate of food production each year.

Supporting the role of nutrients in the food security puzzle. I know that most of our cooperators are well aware of the role that nutrients play in achieving high yields and quality in our food crops. Nowhere in the world is this more evident than in South Asia. Over the past 20 years, IPNI has worked with Universities and Government Agencies in the region to show that the issue of nutrient deficiency is a multi-nutrient challenge, not just an N, P, or K issue. Secondary and micronutrients have become a major deficiency once these macronutrients are addressed, indicating the low levels of indigenous soil fertility common in the region. The ever so commonly cited "yield stagnation" plaguing South Asia is a classic example of how far we have to go in building our crop production efforts in the absence of adequate supplies of all nutrients.

Building a better equipped tool box is what is needed. The number of crop diagnostic and production technologies available today is really quite significant, as is the problem in picking which one to use. However, I think the real challenge is finding those tools which can be effectively, and economically, implemented on small farms in South Asia. Optical sensors may be seen as a powerful tool for improving nitrogen use efficiency, but what happened to the leaf color chart? At IPNI, we have made a commitment to evaluate the Nutrient Expert decision support tool for maize and wheat. Current field research indicates that there may be potential to develop and deliver fertiliser recommendations which are more site-specific for individual farmer fields, in the absence of soil testing. As with all tools, verification is critical, along with finding the partners who can use the technology to help in making recommendations that cater to individual farmer needs.

We continue in our efforts, and remain optimistic that we have the tools to build on higher yields to help achieve the food security goals in South Asia.

Johnston.

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