BETTER CROPS–INDIA

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In This Issue...

Economic Viability of SSNM in Rice-Wheat Cropping

Balanced Fertilisation for Cassava

Improving Sugarcane Productivity through Balanced Nutrition

...and much more

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BETTER CROPS–INDIA

Volume 2, Number 1, December 2008

Our cover: Winter rice planting in Jharkhand State, India.

Photo by Dr. Kaushik Majumdar, IPNI India Programme.

BETTER CROPS-INDIA is a publication of the International Plant Nutrition Institute (IPNI). The mission of IPNI is to develop and promote scientific information about the responsible management of plant nutrition for the benefit of the human family.

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Important Staff Changes for IPNI India Programme

The International Plant Nutrition Institute (IPNI) has announced a series of significant changes to the India Programme staff. The announcement came from IPNI President Dr. Terry L. Roberts and Dr. Adrian Johnston, IPNI Vice President, Asia and Oceania Group.

Effective January 1, 2009, **Dr. Kaushik Majumdar** will be appointed to the position of Director of the India Programme. Dr. Majumdar succeeds **Dr. K.N. Tiwari**, who served as Director of the India Programme since 1998 and retires from IPNI effective December 31, 2008. IPNI leaders also announce the appointment of two new Deputy Directors in India. **Dr. Harmandeep Singh Khurana** will have responsibility in India-West Zone, while **Dr. T. Satyanarayana** will work in India-South Zone and Sri Lanka. **Dr. T. Nagendra Rao** resigned from the India Programme staff in October 2008.

Dr. Majumdar

Dr. Majumdar is a native of West Bengal and has served as IPNI Deputy Director, India-East Zone, since 1999. He received his B.Sc.(Ag) Hons. degree from Visva-Bharati University in 1984, M.Sc. (Ag) in Agriculture Chemistry and Soil Science from Bidhan Chandra Krishi Viswavidyalaya (BCKV) in 1987, and Ph.D. from Rutgers University in Soil Mineralogy and Soil Chemistry in 1993. Dr. Majumdar returned to BCKV as a research associate in 1994, and then joined the Potash Research Institute of India from 1995 to 1999 where he worked on K mineralogy and dynamics in Indian soils. Since joining IPNI, Dr. Majumdar has been based in Kolkata and actively involved in all aspects of program activities in eastern India and Bangladesh.

Dr. Khurana

Dr. Khurana officially joined the staff of IPNI as Deputy Director, India Program-West Zone, effective July 1, 2008. He received his Ph.D. in 2005 in Soils at Punjab Agricultural University (PAU), in Ludhiana, India. He earlier earned his Masters degree in 2001 and B.S. in 1999 at the same university. From 2006 until 2008, Dr. Khurana was Postdoctoral Associate, Soil Fertility and Plant Nutrition, in the Department of Crop and Soil Environmental Sciences at Virginia Tech, Blacksburg. In that responsibility, he modified and tested a soil-water-plant-atmosphere simulation model related to site-specific management and analyzed the fate of excess N in soil and water. From 2005 to 2006, he served on the staff at PAU as an Assistant Professor, Soil Fertility and Plant Nutrition, with 100% research responsibility. Dr. Khurana has received numerous awards and recognition for academic and research achievements, and is the author or co-author of several research publications.

Dr. Satyanarayana

Dr. Satyanarayana joined the staff of IPNI as Deputy Director, India Programme-South Zone, effective November 1, 2008. In 2005, Dr. Satyanarayana received his Ph.D. degree from the Indian Agricultural Research Institute (IARI) in New Delhi. He received his M.Sc. degree at Dr. Y.S.P.U.H. & F. in Himachal Pradesh in 2001, and his B.Sc. Ag. from Tamil Nadu Agricultural University in 1998. Most recently, Dr. Satyanarayana was Deputy Manager-Business Development & Agri Technical Services, with Shriram Fertilizers & Chemicals, DSCL. In that role, he was involved with identifying emerging trends in agriculture and other allied businesses, imparting training, developing publications and coordinating the functioning of 110 Shriram Krishi Vikas Kendras (SKVKs). From 2005 to 2007, he worked as Deputy Manager–Regulatory Affairs, with Coromandel Fertilisers Ltd. in Hyderabad. Dr. Satyanarayana was also a Senior Research Fellow at IARI from 2001 to 2002 and worked on projects related to the rice-wheat cropping system. He is author or co-author of several research publications.

Dr. Tiwari

Dr. Tiwari joined the staff of the PPI/PPIC (now IPNI) India Programme as Deputy Director in June 1998 and was named Director on July 1, 1998. During his 10 years with PPI/PPIC and IPNI, Dr. Tiwari provided leadership in developing information on fertiliser management practices in India which can be readily transferred to farmers to improve yield, quality, and profitability. He also provided training opportunities for scientists, extension workers, fertiliser industry personnel, agricultural students, farmers, and children. A prolific writer, Dr. Tiwari released a large number of scientific and extension publications on the impact of balanced fertiliser use on crop production, profitability, and food security in India. BC INDIA

Introduction to this Special Issue

Welcome…You are reading the second issue of *BETTER CROPS-INDIA*, first introduced in December 2007 and published by the International Plant Nutrition Institute (IPNI). Following a similar style as our popular quarterly publication, *Better Crops with Plant Food*, this special publication is the result of considerable effort by the IPNI India Programme staff and other cooperators.

We at IPNI wish to congratulate and thank the many cooperators, researchers, government officials, farmers, industry representatives, and others who are working in a positive mode for progress in India. — Dr. Terry L. Roberts, President, IPNI

A Global Framework for Fertiliser BMPs

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

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

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

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

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

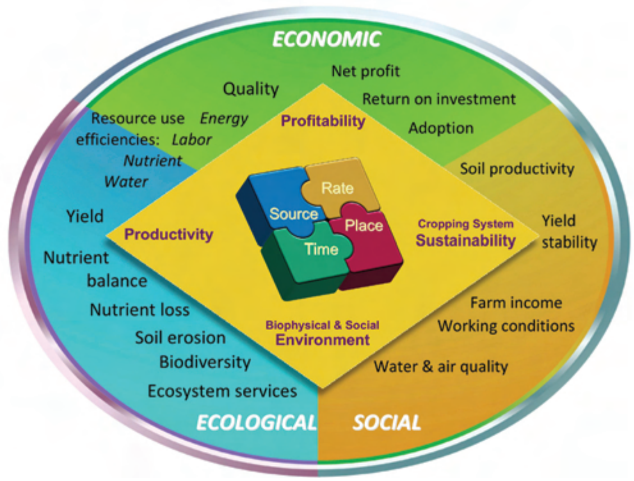

Figure 1. Illustration of a global framework for BMPs for fertiliser use. Fertiliser use BMPs—applying the right nutrient source at the right rate, time, and place—integrate with agronomic BMPs selected to achieve crop management objectives of productivity, profitability, sustainability, and environmental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

Cropping System Management Objectives

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

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

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

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

Fertiliser Management Objectives

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

Scientific Principles

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

Abbreviations and notes for this article: N = nitrogen; P = phosphorus; K = potassium; PPSE = productivity, profitability, sustainability, and environmental health both global and applicable at the practical farm management level. The application of these scientific principles may differ widely depending on the specific cropping system under consideration. **Specific principles relevant to each category of BMPs are listed below.**

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

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

Performance Indicators

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

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

Conclusion

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

Dr. Bruulsema, Dr. Witt, Dr. García, Dr. Li, Dr. Chen, and Dr. Ivanova are IPNI scientific staff located in various regions of the world. All are members of the BMP Working Group of IPNI. Dr. Rao was formerly Deputy Director, IPNI India Programme–South Zone. Contact: Tom.Bruulsema@ipni.net.

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

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

Acknowledgment

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

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

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Two Outstanding Graduate Students in India Receive IPNI Scholar Awards for 2008

The International Plant Nutrition Institute (IPNI) presents its Scholar Award to deserving graduate students in sciences relevant to plant nutrition and management of crop nutrients. Two outstanding individuals at universities in India are among the 2008 honorees recently announced. They are: **I. Vimal Jothi** of Agricultural College and Research Institute, Killikulam, Tamil Nadu Agricultural University (TNAU), and **Wasim Iftikar** of Palli Siksha Bhavana, Visva Bharati University.

Recipients of the IPNI Scholar Award receive a check in the amount of US$2,000 (two thousand dollars) and a certificate. The award is granted directly to the student independent of any assistantship, scholarship, or other award that the individual might hold.

"We received a significant number of applications for the Scholar Awards and were impressed with the qualifications and academic records of the applicants," said Dr. Terry Roberts, IPNI President. "This is a credit to the universities and institutions where these students are pursuing advanced degrees, and also speaks well of their major professors and advisors."


I. Vimal Jothi

Ms. I. Vimal Jothi has been involved in doctoral studies for the past 2 years with the thesis title of "Effect of Neem-Coated Nitrogen Use Efficiency, Yield, and Quality of Sugarcane." She completed her B.Sc. degree in 2003 and M.Sc. degree in 2005, also at TNAU. Her M.Sc. work focused on slow release fertilisers in rice. Her study now seeks to address the problem of storing more N in soils of arid and semi-arid regions, which is complicated by limitations in build-up of soil organic matter. Approaches that help slow mineralisation rate of fertiliser sources can increase immobilisation rate and subsequently slow release of N. The result is higher N utilisation by plants. She has investigated delaying the hydrolysis and nitrification of urea by treating with neem, a natural nitrification inhibitor. In her final year of study, research will establish the mineralisation pattern and associated N losses of neem products under lab and field conditions. This includes measuring ammonia volatilisation losses, ammonification rate, and nitrification rate from soil incubated in a controlled system. For the future, Ms. Jothi hopes to encourage adoption of new technologies by farmers while protecting the soil resource.


Wasim Iftikar

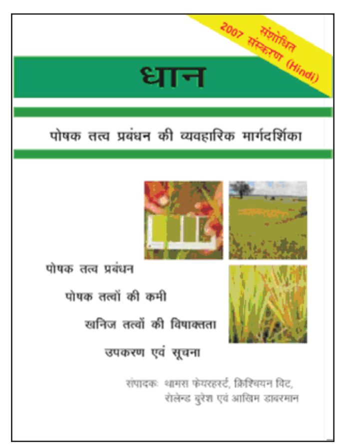
Mr. Wasim Iftikar completed his B.Sc. in Agriculture and M.Sc. degree in Agronomy at Visva Bharati University and recently began pursuing a Ph.D. through a programme called "Studies on Geographic Information System (GIS) Based Soil Fertility Mapping for Nutrient Management in Red and Lateritic Soils". Its objectives include assessment of spatial variability, comparing the relative efficiency of GIS map-based soil fertility evaluation system to conventional soil testing for native fertility prediction in farmer fields, and exploring use of GIS maps in site-specific nutrient management in the rice-potato-sesame cropping sequence. He has also worked as a research fellow on an IPNI-supported programme called "Importance of Soil Test Based Nutrient Application through Farmers' Participatory Approach in Red and Lateritic Zones of West Bengal." For the future, Mr. Iftikar is well aware of the challenge India will face in achieving the estimated 300 million metric tons of annual food grain production needed by the year 2025. He is optimistic that GIS-based soil fertility mapping and other innovative practices will be effective in achieving progress. He also hopes to build on his extensive involvement in sports and community activities as tools in furthering goals related to food production through educational programs. BC INDIA

Abbreviations and notes for this article: N = nitrogen;

Rice: A Practical Guide to Nutrient Management 2nd Edition Now Available in Hindi

Through an agreement of the International Potash Institute (IPI) with the International Rice Research Institute (IRRI) and the International Plant Nutrition Institute (IPNI), the English version of *Rice: A Practical Guide to Nutrient Management* (2nd Edition), by T.H. Fairhurst, C. Witt, R.J. Buresh, and A. Dobermann (eds), 2007 (ISBN 978-981-05-7949-4) was recently translated to Hindi by Dr. B. Mishra, G.B. Pant University of Agriculture and Technology (G.B. PUAT), Pantnagar, India. The Hindi translation (ISBN: 978-3-9523243-3-2; DOI: 10.3235/978-3-9523243-3-2) will soon be ready for distribution.

The publication sells for US$10.00 and orders can be placed at the IPI website: >www.ipipotash.org<. BC INDIA



Balanced Fertilisation for Cassava

By S. Kamaraj, R. Jagadeeswaran, V. Murugappan, and T. Nagendra Rao

While cassava is an important crop for the northwestern agro-climatic zone of Tamil Nadu, most farmers under-fertilise this crop. This study indicates that significant yield improvements are possible given an adequate and balanced application of macronutrients, secondary nutrients, and micronutrients.

Cassava has gained importance as a cheap source of carbohydrate in India, used mostly for human consumption. Apart from its role as a staple food, during the past few decades there has been growing recognition of the value of cassava tubers as a low cost energy source for livestock and as a raw material for industrial and fuel alcohol. More than 800 starch and sago industries operate in and around Salem and Namakkal districts of Tamil Nadu. The added value realised from industrial cassava makes this crop one of the most profitable choices for farmers.

While cassava grows in poor soils, the crop responds well to the application of fertilisers. The majority of cassava farmers do not follow balanced fertilisation practices and there is an opportunity to increase yields and crop economics through balanced fertiliser use. No systematic effort has been carried out to formulate a balanced fertiliser schedule for cassava in the north-western agro-climatic zone of Tamil Nadu. Generally N, P, and K are the most common nutrients taken into consideration in any fertilisation schedule, but information on response to other nutrients is missing altogether.

In order to generate a balanced fertiliser schedule for optimum yields of cassava, two field experiments were conducted in farm fields near the villages of Puthiragoundanpalayam and Paravakkadu in Tamil Nadu. The soils of these experimental sites were sandy clay loam (Thulukkanur Series) and sandy loam (Salem Series), respectively. Both soils are classified as Typic Ustropepts. Both experiments were simultaneously conducted in the same season and year in order to get confirmatory results.

Comparison of farmer practice (left) against an improved treatment on the right.

Table 1. Initial soil analysis of cassava experiments

Parameter	Puthiragoundanpalayam	Paravakkadu
Coarse sand, %	43	51
Fine sand, %	13	13
Silt, %	8	13
Clay, %	36	23
Texture	Sandy clay loam	Sandy loam
pH	7.9	8.1
EC, dS/m	0.13	0.19
CEC, cmol/kg	19.8	16.5
Organic C, %	0.53	0.75
$KMnO_4$-N, kg/ha	176	204
Olsen P, kg/ha	7.8	9.0
NH_4OAc-K, kg/ha	230	170
Exchangeable-Ca, cmol/kg	7.4	9.4
Exchangeable-Mg, cmol/kg	3.0	5.1
$CaCl_2$-S, kg/ha	27	42
DTPA-Zn, mg/kg	0.4	0.5
Hot water soluble-B, mg/kg	2.0	2.2

Soil samples (0 to 15 cm) were taken from experimental plots prior to planting and were analyzed for pH, EC, and CEC (Jackson, 1973), $KMnO_4$-N (Subbiah and Asija, 1956), Olsen-P (Olsen et al., 1954), and NH_4OAc-K (Stanford and English, 1949). The soil at Puthiragoundanpalayam was non-saline with a pH of 7.9 and CEC of 19.8 cmol/kg (**Table 1**). At Paravakkadu, the soil was non-saline with a pH of 8.1 and CEC of 16.5 cmol/kg. Available soil N and P were low and K availability was medium at both locations.

The fertiliser rates for N, P, and K consisted of 60, 90, or 120 kg N/ha; 30, 60, 90, or 120 kg P_2O_5/ha; and 80, 160, 240, or 320 kg K_2O/ha. Calcium, S, Zn, and B were also included based on soil testing and a targeted yield-based requirement. Crops received half the N and K as a basal dressing and half as a top-dressing 90 days after planting. The entire quantities of P, Zn, and B were applied during the basal application. Calcium was supplied through a gypsum application 90 days after planting. Sulphur was supplied incidentally through gypsum or zinc sulfate. Elemental S, calcium oxide, and zinc oxide were used as was required in the respective treatments.

Table 2 presents yield response data of the test crop cultivar CO-2 to incremental rates of N, P, and K, given non-limiting supplies of all other applied nutrients. Cassava responded significantly to N, P, and K application at Puthiragoundanpalayam, while the Paravakkadu site had significant responses to P and K. Yield under the complete "optimum" treatment was 52.4 t/ha at Puthiragoundanpalayam and 48 t/ha at Paravakkadu.

Abbreviations and notes for this article: N = nitrogen, P = phosphorus, K = potassium, Ca = calcium, S = sulphur, Zn = zinc, B = boron, EC = electrical conductivity, CEC = cation exchange capacity.

Table 2. Cassava tuber yield response to major nutrients.

Treatments	Puthiragoundanpalayam		Paravakkadu	
	Yield, t/ha	Yield increase, %	Yield, t/ha	Yield increase, %
N^a_{60}	42.0	–	45.2	–
N_{90}	52.4	25	48.1	6
N_{120}	46.7	11	45.8	1
C.D. (5%)	5.7		NS[d]	
P^b_{30}	40.0	–	38.9	–
P_{60}	40.9	2	45.5	17
P_{90}	52.4	31	48.1	24
P_{120}	44.7	12	45.8	18
C.D. (5%)	4.5		4.2	
K^c_{80}	37.9	–	34.9	–
K_{160}	43.0	14	42.9	23
K_{240}	52.4	38	48.1	38
K_{320}	48.2	27	46.8	34
C.D. (5%)	4.5		3.3	

[a]Common doses: 90 kg P_2O_5, 240 kg K_2O, 47 kg Ca, 40 kg S, 6 kg Zn, and 1 kg B/ha
[b]Common doses: 90 kg N, 240 kg K_2O, 47 kg Ca, 40 kg S, 6 kg Zn, and 1 kg B/ha
[c]Common doses: 90 kg N, 90 kg P_2O_5, 47 kg Ca, 40 kg S, 6 kg Zn, and 1 kg B/ha
[d]NS: not significant
C.D. denotes critical difference

Variation in response to optimum fertilisation at the two locations is likely a result of soil textural differences. Optimum fertilisation was also compared against treatments omitting Ca, S, Zn, and B in order to isolate the individual response to secondary and micronutrients (**Table 3**). At Puthiragoundanpalayam, yield decreased by 15, 6, and 20% with omission of Ca, S, and Zn, respectively. Similarly, yield declined by 12, 9, and 7% without Ca, S, and Zn application at Paravakkadum. The omission of B had no significant influence on cassava tuber yield at either site.

Table 3. Influence of fertiliser treatments on cassava tuber yield.

Treatments	Tuber yield, t/ha	
	Puthiragoundampalayam	Paravakadu
$N_2\,P_3\,K_3$ SM[†]	52.4	48.1
$N_2\,P_3\,K_3$ SM (-Ca)	44.7	42.5
$N_2\,P_3\,K_3$ SM (-S)	49.5	43.8
$N_2\,P_3\,K_3$ SM (-Zn)	41.8	44.6
$N_2\,P_3\,K_3$ SM (-B)	54.4	49.4
SEd	1.57	1.29
C.D. (5%)	3.20	3.55

C.D. denotes critical difference
[†]M denotes micronutrients

The two soils in this study were low in available N and P and therefore cassava responded significantly to their addition. As a tuber crop, cassava removes large amounts of soil K, hence there was marked increase in the yield due to K addition. Given these responses, uptake of N, P and K were significantly reduced in plots not receiving Ca, S, or Zn (**Table 4**).

Table 4. Effect of fertiliser treatments on total N, P, and K uptake in cassava.

Treatments	Total plant uptake, kg/ha					
	Puthiragoundampalayam			Paravakadu		
	N	P	K	N	P	K
$N_2\,P_3\,K_3$ SM[†]	241	34.0	224	211	41.3	259
$N_2\,P_3\,K_3$ SM (-Ca)	206	31.3	187	181	36.2	219
$N_2\,P_3\,K_3$ SM (-S)	199	31.5	204	175	36.4	224
$N_2\,P_3\,K_3$ SM (-Zn)	197	30.2	170	189	36.8	224
$N_2\,P_3\,K_3$ SM (-B)	255	38.7	225	210	40.4	257
SEd	10.3	0.81	15.9	6.48	1.10	8.17
C.D. (5%)	21.1	1.66	32.4	13.2	2.24	16.7

C.D. denotes critical difference
[†]M denotes micronutrients
N_2 = 90 kg/ha, P_3 = 90 kg P_2O_5/ha, K_3 = 240 kg K_2O/ha

Summary

This experiment has facilitated a standardised balanced fertiliser schedule for cassava grown in the northwestern agro-climatic zone of Tamil Nadu. Cassava responded well to the increased level of fertilisers up to 150% of the currently recommended rate along with balanced additions of Ca, S, and Zn. The present investigations clearly indicate a need for an upward revision of the existing blanket recommendation of 60 kg N, 60 kg P_2O_5, and 160 kg K_2O/ha. In its place, a generalised requirement of 90-90-240 kg N-P_2O_5-K_2O/ha plus 47 kg Ca/ha, 40 kg S/ha, and 6 kg Zn/ha is suggested for high yielding cassava within the region. BC-INDIA

Dr. Kamaraj was a research scholar, Dr. Jagadeeswaran is Assistant Professor and Dr. Murugappan was Director, Soil and Crop Management Studies, Tamil Nadu Agricultural University. Dr. Rao was formerly Deputy Director, IPNI-India Programme-South Zone.

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FieldTrialGIS: A Geo-reference Mapping and Data Management System Developed for Agronomic Field Trials

By Gavin Sulewski and T. Nagendra Rao

The challenges of effective storage, management, and presentation of field trial data led to the development of FieldTrialGIS. This system integrates database software with an interactive web-based mapping service. Field data from south India demonstrates the potential capabilities of this working model.

Data management of field trials has been a challenge to agronomists and extension specialists while appropriately archiving, displaying, and analysing the vast amount of information that can be generated from these activities. Our experience has been that the pains taken and money spent on organising trials, collecting data, and the subsequent analysis are at risk of becoming a point of short-term market development interest only. Over time, there is a tendency to lose track of data from individual sites or to consider it obsolete or irrelevant. Given an adequate data management system, the collective power of field trial data should prove its value in identifying gaps in research—both in terms of subject matter and geographical location, as well as identifying trends in yield response, gaps in productivity, economic viability of nutrient application, or spatial and temporal trends in soil fertility.

The objectives set for the project were to standardise data input, arrange and archive data efficiently for easy retrieval, standardise site evaluation through programmed data analysis, and provide a dynamic and interactive web-based interface which can display both the scope of the data collection and key results from the site evaluations. The project began with available documented results from a network of field demonstrations with site data. This project has continued to evolve and become more refined in its design and presentation. Each revision has added new ideas into its design and the potential for incorporating more functions and outputs has not likely been fully explored to date.

Data Requirements and Flow

The data collection process is initiated by providing field research collaborators with a standard form designed to gather a list of key data from each experimental site. This core data set includes: basic descriptive information, soil test data, details on the series of fertiliser treatments, the resulting yields, and individual price data for all nutrients applied and crops harvested. Presently the system facilitates comparisons of any four treatments. Field workers are asked to provide a global position for the site using equipment now commonly available.

Use of electronic collection forms facilitates a simple integration of the site data into a Microsoft® Access™ database. Once imported, each site is subjected to a series of programmed queries which compose the treatment comparisons for yield, economic viability, partial nutrient balance, and nutrient use efficiency (specifically calculated as partial factor productivity

Table 1. Compiled yield and income data from FieldTrialGIS for a total of 67 field sites conducted in southern India.

	Farm practice			Generalised state recommendation			Site-specific nutrient management		
	Yields, kg/ha	Net income, Rs/ha		Yields, kg/ha	Net income, Rs/ha		Yields, kg/ha	Net income, Rs/ha	
Crop (Sites)	Mean	Mean	Range	Mean	Mean	Range	Mean	Mean	Range
Chickpea (10)	2,043	35,232	33,808–36,555	2,271	39,553	35,395–58,615	2,570	42,960	40,260–46,020
Chili (5)	1,928	51,741	49,419–54,860	2,124	56,922	51,490–60,450	2,374	61,940	59,028–64,908
Cotton (5)	2,136	35,716	32,603–37,642	2,434	40,752	38,880–42,480	2,830	45,445	43,825–47,425
Maize (10)	6,130	27,114	23,357–31,262	6,740	29,845	26,190–33,600	8,140	33,028	28,384–36,288
Rabi Sorghum (10)	2,045	15,666	14,749–17,320	2,281	17,173	16,045–18,125	2,739	19,102	17,670–20,310
Rice (7)	6,191	35,162	18,474–47,057	6,929	39,238	21,554–55,675	7,794	42,723	21,533–59,565
Sunflower (10)	2,019	21,777	19,972–23,702	2,304	24,933	23,085–26,565	2,755	27,279	24,699–28,899
Wheat (10)	3,045	25,262	22,370–28,040	3,358	27,200	24,105–28,785	3,886	30,804	28,770–33,360

Abbreviations and notes for this article: N = nitrogen, K = potassium.

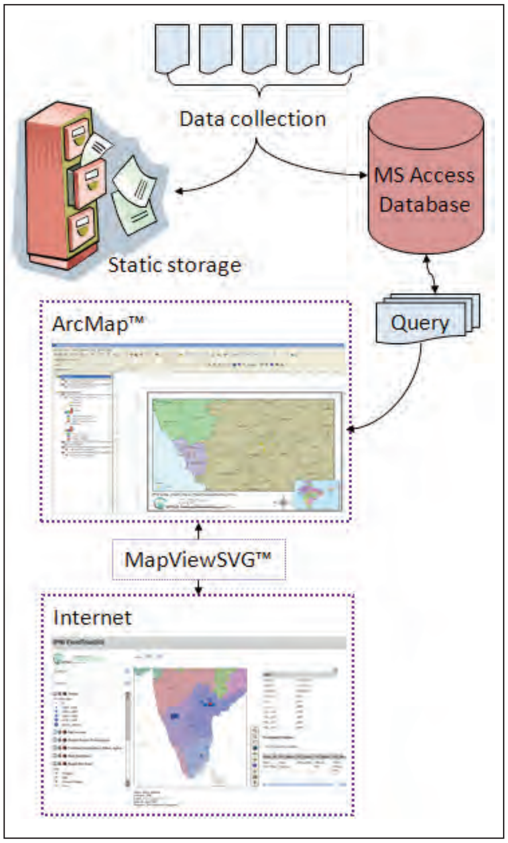

Figure 1. Schematic representing the flow of data for the FieldTrialGIS. Data is diverted from static storage into Access and the GIS data layers are based upon its query results. The web-based product is uploaded via export, using MapViewSVG™ software.

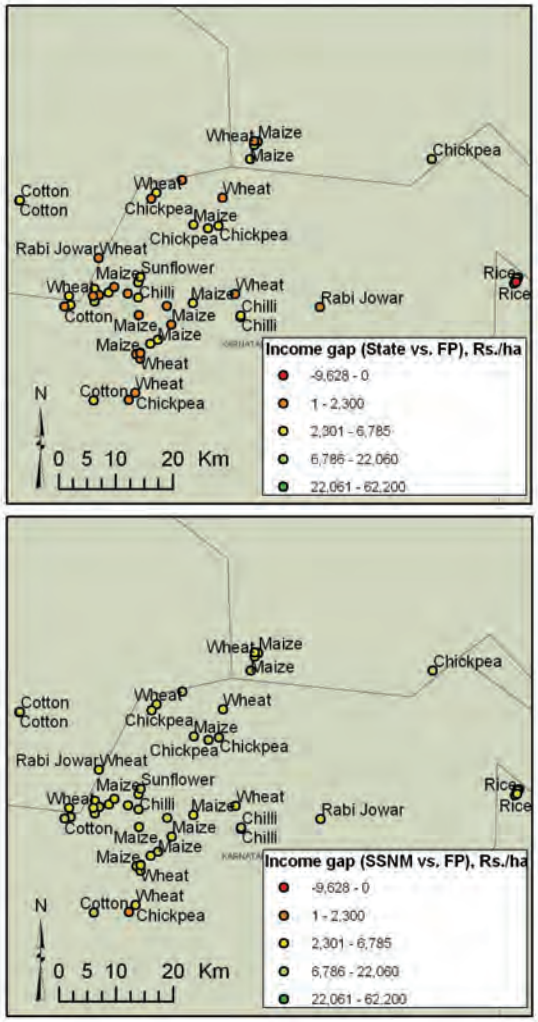

Figure 2. Comparison of the net income gaps between the State recommendation and farmer practice (top) and SSNM and farmer practice (bottom) for a selected group of field demonstrations sites located in Dharwad District, Karnataka.

for N). This series of queries is linked to a Desktop GIS via ESRI®ArcMap™. Finished maps are, in turn, exported via uismedia®MapViewSVG™ and uploaded to an internet environment (**Figure 1**).

The web environment allows for user interactivity through a number of embedded tools supporting the selection of data points and querying of data layers to obtain filtered attribute tables of results. The map window includes a selectable legend used to activate any data layer. Most layers include an attribute table, and an ability to make a GIS data query. One can zoom and pan using toolbar selections, or one may use pre-defined bookmarks and quickly "Zoom to" desired features. The attributes of any feature are available by mouse click, which appear as either a Table or Chart.

Evaluation of FieldTrialGIS

FieldTrialGIS was evaluated using available datasets collected from 67 field trials conducted by collaborating institutions within the peninsular region of south India, including the States of Andhra Pradesh, Karnataka, and Tamil Nadu. The non-replicated demonstrations largely included treatments evaluating site-specific nutrient management (SSNM), a generalised state recommendation, and a common farmer practice. **Table 1** presents a summary which isolates results from field sites comparing the treatments. Crop-wise yields and net incomes are highlighted for data collected between 2005 and 2007. Averaged across sites and years, SSNM has consistently improved yields and incomes for a range of crops compared to either the traditional farmer practice or generalised fertiliser recommendation for the state.

The use of the GIS allows for the data to be projected spatially. For example, in the case of profitability, a visual assessment of the relative effectiveness of State or SSNM fertiliser recommendations at raising the income potential for a region can be obtained (**Figure 2**).

Testing has found the system to be effective from data entry to the generation of its interactive map output. The database has been supplemented with field sites located elsewhere in Asia and there is potential to expand the scope of data coverage to a global-scale. Readers are encouraged to view the program's results available to date. Please find the link to FieldTrialGIS within the IPNI India Programme Portal found at http://www.ipni.net/ipniweb/portal.nsf/dx/India

Important notes on viewing SVG maps Firefox™, Opera™ or Safari™ users do not need the SVG plug-in to see SVG maps while Internet Explorer™ users have to install a free browser plug-in. The free Adobe® SVGViewer is the best to use with Internet Explorer™ which is available at http://www.adobe.com/svg/viewer/install/ BC-INDIA

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Improving Sugarcane Productivity through Balanced Nutrition with Potassium, Sulphur, and Magnesium

By V.K. Singh, A.K. Shukla, M.S. Gill, S.K. Sharma, and K.N. Tiwari

The prime concern of cane growers and the sugar industry is to achieve higher sugarcane productivity and high sugar recovery both of which support maximum economic return. In India, widely varying soil fertility domains is a major limitation to reaching this goal. The results of on-farm experiments conducted during 2003-04 and 2004-05 have clearly established that productivity can be significantly improved when balancing N and P use with K, S, and Mg.

India is a major sugarcane growing country, with production of about 281 million metric tons (M t) from a production area of approximately 4.2 M ha. Sugarcane occupies 51% of the total cultivated area of Uttar Pradesh, with a large number of supporting sugar factories. Despite large total production of sugarcane in the state, average productivity (58.2 t/ha) is lower than the national average of 66.9 t/ha (Indian Sugar, 2008). The productivity of the crop is low mainly due to its late planting after wheat harvest (April to May). A short growing period, coupled with inadequate and imbalanced fertiliser use, make the crop more susceptible to shoot borer infestation and other pest problems.

A recent farmer participatory survey conducted by the authors revealed that growers generally apply >200 kg N/ha and 45 to 60 kg P_2O_5/ha. However, use of K, secondary nutrients, and micronutrients is altogether missing. Farmers are experiencing declining responses to N and P due to omission of other essential nutrients in their fertiliser schedules. Adoption of balanced and judicious use of all needed nutrients can help improve cane productivity and enhance sugar recovery by rendering resistance against biotic and abiotic stresses, and better synthesis and storage of sugar (Yadav et.al., 1993). Farmers are reluctant to shift cane planting time to the spring season (February to March) and sacrifice staple wheat crops intended for human and animal use. Therefore, participatory on-farm experiments were planned to enhance the productivity of late planted sugarcane through fertiliser management including K, S, and Mg application along with N and P.

On-farm experiments were conducted at 10 locations in the Meerut district of western Uttar Pradesh during 2003-04 and 2004-05. The soils were sandy loam to loamy sand in texture, neutral to slightly alkaline in reaction (pH 6.4 to 8.1), low in EC (0.34 to 0.38 dS/m) and available N (76 to 103 mg/kg), and medium in available P (5.4 to 9.1 mg/kg) and K (64 to 99 mg/kg). Each experimental site served as one replication thus the six treatments were evaluated as 10 replications in both study years (**Table 1**). Nutrient application rates were determined based on soil testing and subsequent crop responses. In treatments 1 through 5, the sources of N, P, K, S, and Mg were: urea (46% N): diammonium phosphate (18% N and 46% P_2O_5); potassium chloride (60% K2O): elemental S; and magnesium sulphate (16% MgO and 13% S). The sixth treatment differed, as the K, Mg, and S rates were supplied through a potassium magnesium sulphate source having 22% K 22% S, and 11% Mg. One third of the N and the entire quantities of P, K, S, and Mg were applied at the time of planting. The remaining N was topdressed in two equal splits (i.e., 50 day after sowing (DAS) and 85 to 90 DAS). Basal application of Zn was uniformly done in all plots using 25 kg zinc sulphate ($ZnSO_4 \cdot 7H_2O$). Other crop management was as per existing farm practice.

Sugarcane production in India can benefit greatly from more balanced nutrition. These plants show symptoms of K deficiency.

The crop was harvested manually at maturity and the yield and yield attributes were recorded. The cane samples from bulk produce were taken and quality parameters [brix (%), pol %, commercial cane sugar CCS (%)] were calculated as per formula given by Spencer and Mead (1963). Juice purity (%) was calculated using the following formula:

$$\text{Purity \%} = (\text{Pol \%} / \text{brix \%}) \times 100 \quad (1)$$

The responses to applied nutrients were computed using the following equation:

$$NR = \Delta Y\ Fn\text{-}1 \quad (2)$$

Where NR is the nutrient response to N, P, K, S, and Mg expressed as kg/kg, ΔY the incremental yield due to fertiliser N, P, K, S, and Mg input, Fn the amount of fertiliser N, P, K, S, and Mg applied. The ΔY, and Fn have been expressed as kg/ha. The economic analysis of different nutrient management options are in terms of total net return, per day economic gain and return due to individual nutrients.

Yield and Yield Attributes

Sugarcane productivity was influenced significantly by fertiliser management. The highest cane yield (111.7 to 112.8 t/ha) was achieved under T6. However, these yields were sta-

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

Table 1. On-farm yield and yield attributes of sugarcane as influenced by balanced fertilisation.

Treatment	Cane yield, t/ha	Plant height, cm	Inter node/cane	Millable cane/m^2	Cane weight, kg	Girth of cane, cm
2003-04						
T_1 N_{200}	61.4	155	10	13	0.84	6.1
T_2 N_{200} P_{100}	79.9	172	12	17	0.90	7.1
T_3 N_{200} P_{100} K_{150}	92.2	174	12	20	0.96	7.4
T_4 N_{200} P_{100} $K_{150}S_{60}$	101.0	183	15	21	1.00	8.1
T_5 $N_{200}P_{100}$ $K_{150}S_{60}$ Mg_{30}	110.6	190	16	24	1.06	8.5
T_6 $N_{200}P_{100}$ K_{150} S_{60} $Mg_{30}^{\dagger}$	111.7	188	16	23	1.08	8.6
2004-05						
T_1 N_{200}	61.1	153	11	12	0.82	6.9
T_2 N_{200} P_{100}	72.7	168	12	15	0.91	7.5
T_3 N_{200} P_{100} K_{150}	85.1	178	15	18	0.96	7.9
T_4 N_{200} P_{100} $K_{150}S_{60}$	96.9	188	16	21	0.99	8.3
T_5 $N_{200}P_{100}$ $K_{150}S_{60}$ Mg_{30}	111.4	194	17	24	1.05	8.7
T_6 $N_{200}P_{100}$ K_{150} S_{60} $Mg_{30}^{\dagger}$	112.8	195	18	24	1.08	8.7
CD at 5%						
2003-04	6.2	5.2	1	1.1	0.02	0.4
2004-05	3.9	3.8	1.3	1.6	0.03	0.3

†Includes a single potassium-magnesium-sulphate source.

tistically at par with T5, which had the same nutrient input from individual K, S, and Mg fertiliser sources (**Table 1**). Yield obtained under T5 was 80 to 83% higher than plots receiving 200 kg N/ha alone (T1). Omission of P, K, S, and Mg from the fertiliser schedule resulted in a marked yield loss, indicating the significance of replenishment of these nutrients for achieving high yield targets. The corresponding yield reduction due to P, K, S, and Mg omissions varied from 18.4 to 11.6 t/ha, 12.3 to 24 t/ha, 8.8 to 11.8 t/ha, and 9.6 to 14.5 t/ha, respectively. The increase in cane yield due to balanced fertilisation is attributed to a larger number of millable canes (24 to 25/m^2), higher cane weight (1.05 to 1.06 kg/cane), wider cane girth (8.5 to 8.7 cm), and larger plant height (190 to 194 cm) (**Table 1**). These results confirm the findings of long-term experiments conducted with different crop sequences at various locations in India, wherein application of N alone depleted the native P, K, S, and micronutrient reserve of soil, thus causing significant yield loss (Swarup and Wanjari, 2000).

Table 2. Agronomic efficiency (AE) of N, P, K, S, and Mg application in sugarcane as influenced by balanced fertilisation.

Treatment	AE, kg sugarcane/kg nutrient[1]				
	N	P	K	S	Mg
2003-04					
T_1 N_{200}	307	–	–	–	–
T_2 N_{200} P_{100}	400	1,816	–	–	–
T_3 N_{200} P_{100} K_{150}	461	2,095	750	–	–
T_4 N_{200} P_{100} $K_{150}S_{60}$	505	2,295	821	1,683	–
T_5 $N_{200}P_{100}$ $K_{150}S_{60}$ Mg_{30}	553	2,514	899	1,848	3,687
T_6 $N_{200}P_{100}$ K_{150} S_{60} $Mg_{30}^{\dagger}$	559	2,538	908	1,862	3,723
2004-05					
T_1 N_{200}	306	–	–	–	–
T_2 N_{200} P_{100}	364	1,652	–	–	–
T_3 N_{200} P_{100} K_{150}	426	1,934	692	–	–
T_4 N_{200} P_{100} $K_{150}S_{60}$	485	2,202	788	1,615	–
T_5 $N_{200}P_{100}$ $K_{150}S_{60}$ Mg_{30}	557	2,532	906	1,857	3,713
T_6 $N_{200}P_{100}$ K_{150} S_{60} $Mg_{30}^{\dagger}$	564	2,564	917	1,860	3,760

[2]Computed based on actual content basis.
†includes a single potassium-magnesium-sulphate source.

Agronomic Efficiency

Agronomic efficiency (kg sugarcane/kg nutrient) was greater in plots with balanced supply of K, S, and Mg along with N and P (**Table 2**). The concomitant increase in N use

Table 3. Quality parameters of sugarcane as influenced by balanced fertilisation.

Treatment	Brix, %	Pol, %	Purity, %	CCS, %	CCS, t/ha
2003-04					
T_1 N_{200}	18.6	15.4	82.8	8.34	5.12
T_2 N_{200} P_{100}	19.8	16.6	83.8	8.79	7.02
T_3 N_{200} P_{100} K_{150}	20.9	18.1	86.6	9.68	8.92
T_4 N_{200} P_{100} $K_{150}S_{60}$	21.2	18.7	88.2	10.05	10.15
T_5 $N_{200}P_{100}$ $K_{150}S_{60}$ Mg_{30}	21.4	19.0	88.8	10.37	11.20
T_6 $N_{200}P_{100}$ K_{150} S_{60} $Mg_{30}^{\dagger}$	21.4	19.4	90.7	10.46	11.68
2004-05					
T_1 N_{200}	19.1	15.3	80.2	7.98	4.88
T_2 N_{200} P_{100}	20.6	16.8	81.6	8.44	6.14
T_3 N_{200} P_{100} K_{150}	21.3	17.8	83.8	9.02	7.68
T_4 N_{200} P_{100} $K_{150}S_{60}$	21.6	18.4	85.3	9.42	9.13
T_5 $N_{200}P_{100}$ $K_{150}S_{60}$ Mg_{30}	21.5	18.5	85.9	9.84	10.69
T_6 $N_{200}P_{100}$ K_{150} S_{60} Mg_{30}†	21.7	18.8	86.6	10.07	11.36
CD at 5%					
2003-04	0.3	0.5	3.1	0.30	0.94
2004-05	0.6	0.4	2.0	0.36	1.01

†includes a single potassium-magnesium-sulphate source

Table 4. Net profit and per day economic productivity of sugarcane as influenced by balanced nutrient management options.

Treatment	Cost of nutrients, Rs*/ha	Gross return, Rs/ha	Net return due to nutrient options, Rs/ha				Per day net economic productivity‡, Rs/ha/day
			Over N	Over NP	Over NPK	Over NPKS	
2003-04							
T_1 N_{200}	2,100	67,540	–	–	–	–	185
T_2 N_{200} P_{100}	3,750	87,890	20,350	–	–	–	241
T_3 N_{200} P_{100} K_{150}	4,875	101,420	33,880	13,530	–	–	278
T_4 N_{200} P_{100} $K_{150}S_{60}$	6,465	111,100	43,560	23,210	9,680	–	305
T_5 N_{200} P_{100} $K_{150}S_{60}$ Mg_{30}	7,897	121,660	54,120	33,770	20,240	10,560	333
T_6 N_{200} P_{100} K_{150} S_{60} Mg_{30}†	10,425	122,870	55,330	34,980	21,540	11,860	337
2004-05							
T_1 N_{200}	2,100	67,210	–	–	–	–	184
T_2 N_{200} P_{100}	3,750	79,970	12,760	–	–	–	219
T_3 N_{200} P_{100} K_{150}	4,875	93,610	26,400	13,640	–	–	257
T_4 N_{200} P_{100} $K_{150}S_{60}$	6,465	105,710	38,500	25,740	12,100	–	290
T_5 N_{200} P_{100} $K_{150}S_{60}$ Mg_{30}	7,897	122,540	55,330	42,570	28,930	16,830	336
T_6 N_{200} P_{100} K_{150} S_{60} Mg_{30}†	10,425	124,080	56,870	44,110	30,470	18,370	340
CD at 5%							
2003-04	–	3,780	–	–	–	–	14
2004-05	–	3,510	–	–	–	–	9

†Includes a single potassium-magnesium-sulphate source.
‡Economic growth rate per day.

efficiency due to P, K, S, and Mg application was in the range of 364 to 557 kg cane/kg nutrient. The increase in efficiency of the individual nutrient was 1,652 to 2,532 kg cane/kg with P_2O_5, 692 to 906 kg cane/kg with K_2O, 1,615 to 1,857 kg cane/kg S, and 3,687 to 3,713 kg cane/kg Mg. Similar evidence was gathered by Ghosh et al. (1990) who reported that S application helped increase cane productivity by way of increased nitrate reductase activity and ultimately higher N use efficiency. Increased nutrient use efficiency with balanced fertilisation indicates that the existing N-driven agriculture cannot sustain high yield goals (Tiwari, 2002).

Effect on Quality

Juice quality viz. brix (%), pol (%), purity (%), and CCS (%) were significantly influenced by fertiliser treatment. The best cane quality parameters were recorded with either T5 or T6 (**Table 3**). The significance of S and Mg application along with adequate NPK was noted for Pol (%) and CCS (%). This improvement in juice quality may be due to an increase in activity of sucrose synthesizing enzymes which also helped increase CCS yield. An improvement in juice quality with the application of P and K has also been reported by Kumar et al. (2002).

Economics

Application of P, K, S, and Mg increased the cost of inputs by Rs.8,325/ha over application of 200 kg N alone but it returned an extra net profit of Rs.55,330 to 56,870/ha. The net economic gain due to individual nutrient application ranged from Rs.12,760 to 20,350/ha for P_2O_5, Rs.13,640 to 13,530/ha for K_2O, Rs.9,680 to 12,100/ha for S, and Rs.10,560 to 16,830/ha for Mg (**Table 4**). Economic productivity per day reached Rs 337 to 340/ha/day, or 1.8 times that obtained under N application alone (Rs.185/ha/day). Daily economic productivity improved the most with the inclusion of P_2O_5 (Rs.46/ha/day) followed by K_2O (Rs.38/ha/day), Mg (Rs.37/ha/day), and S (Rs.30/ha/day). Application of K, S, and Mg through the sole source product had a small edge over T5. Thus K-S-Mg supply can be effectively maintained through the potassium-magnesium-sulphur source in case of the lack of availability of straight fertiliser, such as potassium chloride, elemental S, and magnesium sulphate.

Conclusion

The results of this study establish the significance of balanced fertilization with K, S, Mg for higher yield, higher sugar recovery, and higher farmer profit with sugarcane in north India. Year-to-year weather variability and location-specific soil fertility variability greatly influence yield and nutrient use efficiency, but this can be minimised through fertiliser best management practices. BC-INDIA

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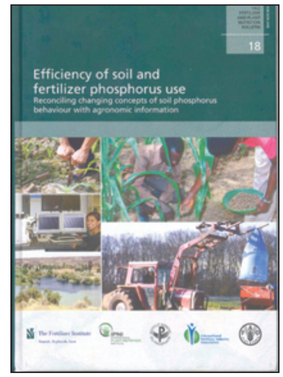

A 2008 publication released by the Fertilizer and Plant Nutrition Group of the United Nations Food and Agriculture Programme (FAO) provides an excellent, up-to-date summary of recent research on the efficiency of soil and fertilizer P use in agriculture. Authored by J.K. Syers of Mae Fah Luang University in Thailand, A.E. Johnston of Rothansted Research in the United Kingdom, and D. Curtin of New Zealand Institute for Crop and Food Research Limited, the publication summarizes recent research results on the efficient use of soil and fertilizer P. The ever-increasing importance of fertilizers in food production around the world, which has been recently highlighted by severe reductions in food grain reserves, provides a very timely release for this publication.

Research related to the behavior of P in soils indicates that inorganic P exists in adsorbed forms in most soils, and becomes absorbed by diffusion into soil components. As a result of the reversible transfer between available and non-available forms of soil P, plant access to soil P is often reduced only temporarily. The report states: "P is largely retained by soil components with a continuum of bonding energies, resulting in varying degrees of reversibility." The authors conclude that when using an appropriate time scale, P recovery values of up to 90% have been recorded, and indicates a high level of P use efficiency over time.

Evaluating soil residual P was an important part of this publication. This residual P contributes to solution P, which is the source of plant P uptake. Because a crop can only take up a portion of P that is applied in the current year, measuring P supply from this fertilizer application over time becomes critical to effectively determining residual P from fertilizer additions. The authors reported that the "balance method" of measuring recovery and efficiency of fertilizer P is the preferred approach as it takes into account residual P in soils. This was preferred over the "difference method", which does not consider residual soil P.

The authors conclude that given the nature of P dynamics in soils…transferring back and forth between available and unavailable forms for plants…understanding the contribution of previously applied P over a long period of time becomes critical to assessing P use efficiency. Long-term experimentation, which considers availability of residual P over a number of years, will provide a truer picture of the efficiency of soil and fertilizer P use. The publication also provides an excellent collection of case studies from various regions around the world detailing the calculation of P recovery.

The book is available from FAO; e-mail: publications-sales@fao.org. Or a PDF copy of the full 108-page publication can be downloaded from the FAO publications website at: >http://www.fao.org/docrep/010/a1595e/a1595e00.htm<. BC INDIA

IPNI Crop Nutrient Deficiency Photo Contest—2009

To encourage field observation and increase understanding of crop nutrient deficiencies and other conditions, the International Plant Nutrition Institute (IPNI) plans to continue sponsorship of a photo contest during 2009.

"We always hope this competition will appeal to practitioners working in actual production fields," said IPNI President Dr. Terry Roberts. "Researchers working under controlled plot conditions are also welcome to submit entries. We encourage crop advisers, and others to photograph and document deficiencies in crops."

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.

There are 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 = US$150 • Second place = US$75 • Third place = US$50.

Photos and supporting information can be submitted until December 15, 2009 and winners will be announced in January of 2010. Winners will be notified and results will be posted on our website. The photos shown here are examples of two winning entries from India which were submitted to the 2007 edition of the contest.

Entries are encouraged from all regions of the world. However, entries can only be submitted electronically as high resolution digital files to the organization's website, at >**www.ipni.net/photocontest**<.

For questions or additional information, please contact:

Mr. Gavin Sulewski, IPNI, Agronomic and Technical Support Specialist, 102-411 Downey Road, Saskatoon, SK S7N 4L8 Canada; phone: 306-652-3535; e-mail: gsulewski@ipni.net BC-INDIA

Nitrogen deficiency in corn (submitted by S. Srinivasan, Tamil Nadu).

Boron deficiency in coconut (submitted by P. Jeyakumar, Tamil Nadu).

Economic Viability of Site-Specific Nutrient Management in Rice-Wheat Cropping

By V.K. Singh, R. Tiwari, M.S. Gill, S.K. Sharma, K.N. Tiwari, B.S. Dwivedi, A.K. Shukla, and P.P. Mishra

The most dominant rice-wheat system of India is showing signs of fatigue, mainly due to inadequate and unbalanced fertilisation. The current productivity can be doubled by growing hybrid rice and locally recommended high-yielding varieties of wheat and by increasing balanced fertiliser application rates to correct multiple nutrient deficiencies which are being widely observed.

The rice-wheat cropping system (RWCS) is the most widely adopted system, covering over 10.5 M ha—mostly in northwest zone (Paroda et al., 1994). The productivity of both rice and wheat is low…2,130 and 2,670 kg/ha, respectively, mainly due to poor soil fertility, inadequate, unbalanced, and inefficient use of fertilisers (Yadav et al., 2000; Dwivedi et al., 2001). Continuous rice-wheat cropping without adequate and balanced nutrition has resulted in a widespread problem of multiple nutrient deficiencies (Timsina and Connor, 2001). A multi-location, on-station research was initiated to evaluate the significance of site specific nutrient management (SSNM) towards breaking yield stagnation. The research considers all existing nutrient deficiencies and correcting them so as meet nutrient requirements of high yield goals.

Field experiments were conducted for 3 years during to 2003-04 to 2005-06 to evaluate the effect of SSNM in rice-wheat cropping systems at 9 locations representing intensive agriculture in northwest India. The deep alluvial soils of the experimental sites were generally sandy loam to loamy sand, but were clayey at Faizabad and Varanasi. Most sites had neutral to slightly alkaline soils (pH 6.0 to 8.2), but were acidic (pH 5.2) at Palampur. Soils were low to medium in available N, K, S, B, and Mn and medium to high in available P and Zn. The initial soil analysis was done by Agro-International, U.S.A. as per methods described by Portch and Hunter (2002). These soil analyses were the basis for developing SSNM recommendations for yield targets of 10 t/ha of hybrid rice and 6 t/ha of wheat.

While SSNM treatments required more investment in fertiliser nutrients, net returns were very favorable.

Selected treatments allowed the assessment of responses to all the deficient nutrients so as to develop viable fertiliser best management practices (BMPs) for high yield sustainable agriculture. The SSNM nutrient packages for each site included all macro, secondary, and micronutrients considered deficient (**Table 1**). Both crops received NPK, while S and micronutrients were applied to rice only. The efficacy of SSNM was compared against a state fertiliser recommendation (SR) and farmers' fertiliser practice (FP). Omission plots for different

Table 1. Experimental location and the nutrient applied in the rice-wheat cropping system.

		Nutrient applied, kg/ha					
		Rice			Wheat		
Location	State	SSNM	SR	FP	SSNM	SR	FP
Sabour	Bihar	$N_{150}P_{30}K_{100}S_{40}$	$N_{100}P_{40}K_{40}$	$N_{60}P_{30}$	$N_{150}P_{30}K_{100}$	$N_{120}P_{60}K_{40}$	$N_{60}P_{30}$
Palampur	Himachal Pradesh	$N_{100}P_{25}K_{80}S_{40}Zn_{20}B_5$	$N_{100}P_{30}K_{30}$	$N_{80}P_{20}$	$N_{100}P_{25}K_{80}$	$N_{100}P_{30}K_{30}$	$N_{80}P_{20}$
Ranchi	Jharkhand	$N_{150}P_{60}K_{100}S_{25}Zn_{30}B_5$	$N_{150}P_{75}K_{60}$	$N_{80}P_{40}K_{20}$	$N_{150}P_{60}K_{100}$	$N_{150}P_{75}K_{60}$	$N_{80}P_{40}K_{20}$
R.S. Pura	Jammu & Kashmir	$N_{150}P_{100}K_{120}S_{50}Zn_{40}Mn_{20}$	$N_{120}P_{60}K_{30}$	$N_{50}P_{30}K_{20}$	$N_{150}P_{100}K_{120}$	$N_{120}P_{60}K_{30}$	$N_{50}P_{30}K_{20}$
Ludhiana	Punjab	$N_{150}P_{60}K_{150}S_{40}Zn_{25}B_5Mn_{20}$	$N_{120}P_{30}K_{30}Zn_{25}$	$N_{180}P_{60}Zn_{10}$	$N_{150}P_{60}K_{150}$	$N_{120}P_{30}K_{30}$	$N_{180}P_{30}$
Faizabad	Uttar Pradesh	$N_{150}P_{60}K_{120}S_{40}Zn_{25}B_5Mn_{20}$	$N_{120}P_{60}K_{60}$	$N_{90}P_{40}$	$N_{150}P_{60}K_{120}$	$N_{120}P_{60}K_{60}$	$N_{90}P_{40}$
Kanpur	Uttar Pradesh	$N_{150}P_{30}K_{120}S_{50}Zn_{40}$	$N_{150}P_{75}K_{60}S_{25}$	$N_{80}P_{30}$	$N_{150}P_{30}K_{120}$	$N_{150}P_{75}K_{60}$	$N_{80}P_{30}$
Modipuram	Uttar Pradesh	$N_{150}P_{30}K_{80}S_{20}Zn_{25}B_5Mn_{20}$	$N_{150}P_{75}K_{75}Zn_{25}$	$N_{180}P_{60}Zn_{25}$	$N_{150}P_{30}K_{80}$	$N_{120}P_{60}K_{40}$	$N_{180}P_{60}$
Varanasi	Uttar Pradesh	$N_{150}P_{30}K_{80}S_{40}Zn_{40}B_5Mn_{20}Cu_{20}$	$N_{150}P_{75}K_{75}Zn_{25}$	$N_{180}P_{60}Zn_{25}$	$N_{150}P_{30}K_{80}$	$N_{120}P_{60}K_{40}$	$N_{180}P_{60}$

The equal levels of P and K are in the form of P_2O_5 and K_2O, Zn, Mn, and Cu are in the form of sulfate and B as borax.

Abbreviations and notes for this article: N = nitrogen, P = phosphorus, K = potassium, S = sulphur, B = boron, Mn = manganese, Zn = zinc.

treatments were maintained to determine the individual responses to specific nutrient application.

Fertiliser sources included urea (46% N), diammonium phosphate (18% N and 46% P_2O_5), potassium chloride (60% K_2O), elemental S, zinc sulphate (21% Zn and 10% S), borax (10.5 % B), manganese sulphate (30.5% Mn, 17.5% S), and copper sulphate (24% Cu, 12% S). Entire quantities of P, K, S, and micronutrients, and one-third of the total N were applied at planting. The remaining N was top-dressed in two equal splits. Hybrid rice cv. PHB 71 and locally recommended high yielding varieties of wheat were grown at all locations.

Economic comparisons for each of the nutrient management options included analysis of gross and net returns, as well as the additional returns per unit investment in each individual crop and the entire RWCS. Agronomic efficiency and economic viability were assessed as well as apparent nutrient recovery on a individual crop and cropping system basis. Results reported here are averages of 3 years of study.

The mean grain yield of rice (unhusked) obtained with the SSNM was 8.20 t/ha as compared to 6.95 t/ha under the SR and 6.03 t/ha under FP (**Table 2**). SSNM out-yielded FP by 2.17 t/ha (+36%). The extra yield obtained with rice through SSNM (over FP) ranged from 1.0 t/ha at Varanasi to 3.27 t/ha at Sabour, indicating an almost three-fold difference among locations. This yield advantage with rice was of the order of 25% or more at 7 out of 9 sites. The SSNM treatment out-yielded FP by more than 2 t/ha at 5 out of 9 locations. Similarly, rice yields under SSNM were 3 t/ha or more than FP at Sabour, Faizabad, and Modipuram. Although SR had a significant edge over FP, the overall response was limited to only 0.92 t/ha (+15%).

Averaged over locations, the grain yield of the succeeding wheat crop was 4.86 t/ha with SSNM against 3.56 t/ha under FP (**Table 2**). Averaged across locations, the SSNM plot out-yielded FP by 1.30 t/ha (+41%). The additional yield obtained with SSNM over FP ranged from 391 kg/ha at Ludhiana to 1,924 kg/ha at Sabour indicating an almost five-fold difference among locations. This yield advantage was 30% or more at 6 out of 9 locations. Similarly, the productivity gain over FP was more than 1.0 t/ha at 7 out of 9 locations. As with rice, a significant yield response for SR was also obtained in wheat and the magnitude of yield increase over FP was 744 kg/ha (+21%).

Table 2. Grain yield response to SSNM and state recommended fertiliser doses over farmer nutrient management practice.

	Rice			Wheat			Rice-wheat system		
		Response			Response			Response	
Treatment	Yield, t/ha	t/ha	%	Yield, t/ha	t/ha	%	Yield, t/ha	t/ha	%
Sabour									
SSNM	8.23	3.27	66	5.18	1.92	59	13.40	5.19	63
SR	6.03	1.07	22	4.55	1.30	40	10.58	2.37	29
FP	4.96	–	–	3.25	–	–	8.21	–	–
Palampur									
SSNM	5.28	1.14	28	3.41	1.26	59	8.70	2.41	38
SR	4.70	5.58	14	2.99	0.84	39	7.68	1.39	22
FP	4.14	–	–	2.15	–	–	6.29	–	–
Ranchi									
SSNM	6.76	2.56	61	4.05	1.47	57	10.80	4.03	60
SR	5.96	1.76	42	3.40	0.82	32	9.36	2.58	38
FP	4.20	–	–	2.58	–	–	6.77	–	–
R.S. Pura									
SSNM	8.40	1.71	26	4.64	1.35	41	13.04	3.06	31
SR	7.38	0.69	10	4.07	0.78	24	11.46	1.47	15
FP	6.69	–	–	3.29	–	–	9.99	–	–
Ludhiana									
SSNM	10.43	1.30	14	6.02	0.39	7	16.45	1.69	11
SR	9.81	0.67	7	5.79	0.16	3	15.60	0.83	6
FP	9.13	–	–	5.63	–	–	14.77	–	–
Faizabad									
SSNM	8.28	3.08	59	4.43	1.75	65	12.71	4.83	61
SR	6.13	0.93	18	3.42	0.74	28	9.55	1.67	21
FP	5.20	–	–	2.68	–	–	7.88	–	–
Kanpur									
SSNM	9.23	2.34	34	5.69	1.15	25	14.91	3.48	30
SR	8.28	1.39	20	5.26	0.73	16	13.55	2.12	19
FP	6.89	–	–	4.54	–	–	11.43	–	–
Modipuram									
SSNM	10.18	3.16	45	6.10	1.55	34	16.28	4.71	41
SR	7.73	0.70	10	5.41	0.86	19	13.14	1.56	14
FP	7.03	–	–	4.55	–	–	11.58	–	–
Varanasi									
SSNM	7.03	1.00	17	4.19	0.81	24	12.46	1.93	18
SR	6.53	0.50	8	3.85	0.47	14	11.61	1.08	10
FP	6.02	–	–	3.39	–	–	10.53	–	–
Mean over locations									
SSNM	8.20	2.17	36	4.86	1.30	41	12.79	3.30	35
SR	6.95	0.92	15	4.31	0.74	21	11.04	1.55	16
FP	6.03	–	–	3.56	–	–	9.49	–	–
CD at 5%	0.59	–	–	0.25	–	–	0.71	–	–

CD = critical difference

The productivity of rice-wheat system, as a whole was highest under SSNM (12.79 t/ha), which was 35% more than FP (9.49 t/ha). The productivity gain due to SSNM in rice plus wheat through SSNM over FP ranged from 1.69 t/ha at Ludhiana to 5.19 t/ha at Sabour, indicating an almost three-fold difference among locations. The productivity gain under SSNM had a yield improvement of 3 t/ha or more at 6 out of 9 locations. The extent of yield increase was more than 4 t/ha at 4 sites including Sabour, Ranchi, Faizabad, and Modipuram.

Economic analysis

SSNM in rice cultivation involved an additional expenditure ranging from Rs.1,140 to 6,210/ha (average Rs.3,550/ha) over FP (**Table 3**). This additional expenditure generated an average extra produce (grain + straw) worth Rs.19,740/ha within a range of Rs.9,130 to 29,670/ha. After deducting additional costs, the resulting average net return was Rs.16,190/ha with a benefit-to-cost ratio (BCR) of 4.6.

In wheat, moving from FP to SSNM involved an additional fertiliser expenditure of Rs.340 to 3,130/ha (average Rs.1,520/ha). Generally, lower additional investment needed for wheat is due to that cost incurred for S and micronutrients application in rice only. Since wheat has also benefited from the residual effects of these nutrients, the net returns have been affected proportionately. The additional net return under SSNM over FP ranged from Rs.4,060/ha at Ludhiana to Rs.22,400/ha at Sabour (**Table 3**). As expected, the improvements in wheat were associated with higher BCRs compared to rice because of high additional input costs debited to rice for S and micronutrients.

The cumulative effect of SSNM under the entire RWCS involved an additional expenditure of Rs.5,070/ha and an additional produce value worth Rs.36,010/ha (gross) and Rs.30,940/ha (net) after deducting the extra input costs. This was achieved at an average BCR of 6.1 which means that every extra rupee invested in nutrients for SSNM over FP produced an extra crop value of Rs.6.1. Any technological improvements with a BCR of 5 would be highly remunerative and suitable for large-scale adoption.

Table 3. Changes in economic returns while shifting from farmer nutrient management practice to SSNM in the rice- wheat cropping system[1].

		SSNM vs farmer practice			
Location	Crop	Extra cost of fertiliser, Rs./ha	Value of extra produce, Rs./ha	Net return, Rs./ha	Benefit-to-cost, Rs. per Rs. invested in nutrients
Sabour	Rice	2,920	29,670	26,750	9.2
	Wheat	1,780	24,180	22,400	12.6
	System	4,700	53,850	49,150	10.5
Palampur	Rice	3,210	10,340	7,130	2.2
	Wheat	1,520	15,890	14,370	9.4
	System	4,730	26,230	21,500	4.6
Ranchi	Rice	3,300	23,290	19,990	6.1
	Wheat	1,780	18,470	16,690	9.4
	System	5,080	41,760	36,680	7.2
R.S. Pura	Rice	1,990	15,510	13,520	1.5
	Wheat	3,130	16,950	13,820	4.4
	System	5,120	32,460	27,340	2.5
Ludhiana	Rice	3,130	11,790	8,660	2.8
	Wheat	840	4,900	4,060	4.8
	System	3,970	16,690	12,720	3.2
Faizabad	Rice	4,440	27,980	23,540	5.3
	Wheat	1,940	22,020	20,080	10.3
	System	6,380	50,000	43,620	6.8
Kanpur	Rice	3,970	21,260	17,290	4.4
	Wheat	1,730	14,500	12,770	7.4
	System	5,700	35,760	30,060	5.3
Modipuram	Rice	1,140	28,660	27,520	24.1
	Wheat	340	19,530	19,190	56.1
	System	1,480	48,190	46,710	31.6
Varanasi	Rice	3,680	9,130	5,450	1.5
	Wheat	630	10,140	9,510	15.0
	System	4,310	19,270	14,960	3.5
Mean over location					
	Rice	3,550	19,740	16,190	4.6
	Wheat	1,520	16,270	14,750	9.7
	System	5,070	36,010	30,940	6.1

[1]Economic analysis based on 2007/08 costs of nutrients and grain/straw values. Fertiliser (Rs./kg): N, 11; P_2O_5, 17; K_2O, 8; S, 28; zinc sulphate, 21; borax, 36; manganese sulphate, 32; copper sulphate, 14. Grain (Rs./kg): rice, 7.2; wheat, 9.7. Straw (Rs./kg): rice, 1.0; wheat, 1.6.

Agronomic efficiency

Agronomic efficiency (AE) expressed as kg grain/kg nutrient was greater in SSNM plots compared to FP and the SR. The concomitant increase in AE was 5.4 to 40.6 kg rice/kg and 5.5 to 32 kg wheat/kg for P_2O_5, and 7.3 to 27.1 kg rice/kg and 2.5 to 13.2 kg wheat/kg for K_2O. The corresponding increase in AE for the RWCS was 7.4 to 34 kg rice/kg P_2O_5 and 8.2 to 12.8 kg wheat/kg K_2O (**Table 4**). Average AE for S and Zn in the RWCS was 33.8 and 46.4 kg/kg, respectively. AE was higher in the case of rice (25.2 and 30.7 kg rice/kg S and Zn) than that for its residual availability in wheat (13.3 and 18.1 kg/kg S and Zn). The economic viability computed in terms of Rs./Re. invested for individual nutrients indicated that Re.1 invested in P_2O_5, K_2O, S, and zinc sulphate gave additional returns of Rs.8.4, Rs.8.3, Rs.8.5, and Rs.14.4, respectively.

Apparent nutrient recovery

Averaging across the locations, the apparent recoveries of P, K, and S in rice (ie., 29%, 51%, and 41%, respectively) were comparatively higher than in wheat, which were 26%, 44%, and 15%, respectively (**Table 5**). Thus, rice recovered

Table 4. Agronomic efficiency (AE) expressed as kg grain/kg of P_2O_5, K_2O, S, and Zn application through SSNM in the rice-wheat cropping system.

	AE_P		AE_K		AE_S		AE_{Zn}	
Site	Rice	Wheat	Rice	Wheat	Rice	Wheat	Rice	Wheat
Sabour	32.0	20.4	12.2	7.5	27.9	15.6	–	–
Palampur	40.6	5.5	12.4	13.3	13.8	16.5	20.8	28.3
Ranchi	30.6	15.8	16.8	5.7	24.6	11.6	14.9	19.1
R.S. Pura	5.4	9.4	10.9	8.9	10.9	12.5	7.0	4.4
Ludhiana	11.4	7.2	7.3	2.5	18.1	2.5	30.1	4.9
Faizabad	28.4	27.0	8.8	9.0	25.4	13.6	59.0	25.6
Kanpur	40.3	27.2	10.8	5.5	36.0	18.8	43.3	21.6
Modipuram	34.4	32.0	27.1	11.7	53.8	20.1	46.7	16.0
Varanasi	27.5	25.5	10.3	8.7	15.9	7.3	24.1	25.2
Mean over location	27.8	18.9	12.9	8.1	25.2	13.2	30.7	18.1

Table 5. Apparent recovery efficiency in maximum economic yield plot fertilised according to SSNM under rice-wheat cropping system.

		Apparent recovery efficiency, %		
Location	Nutrient	Rice	Wheat	RWCS
Sabour	P_2O_5	29	27	28
	K_2O	60	51	55
	S	39	12	50
Palampur	P_2O_5	24	21	22
	K_2O	42	40	41
	S	37	11	48
Ranchi	P_2O_5	25	17	21
	K_2O	50	36	43
	S	28	19	47
R.S. Pura	P_2O_5	22	18	20
	K_2O	47	44	46
	S	40	16	57
Ludhiana	P_2O_5	31	29	30
	K_2O	54	47	51
	S	46	14	60
Faizabad	P_2O_5	31	30	31
	K_2O	55	38	47
	S	47	6	53
Kanpur	P_2O_5	38	36	37
	K_2O	47	47	47
	S	37	22	59
Modipuram	P_2O_5	32	28	30
	K_2O	45	35	40
	S	45	16	61
Varanasi	P_2O_5	28	24	26
	K_2O	59	53	56
	S	49	16	65
Mean over location	P_2O_5	29	26	27
	K_2O	51	44	47
	S	41	15	56
CD at 5%		5	5	5

most of the in-crop S application and recoveries were much lower in wheat. For the RWCS, the apparent recoveries of P, K, and S were 27%, 47%, and 56%, respectively. Increased recovery efficiency under SSNM plots reveals that existing N or NP-driven agriculture cannot sustain high yield agriculture. Adequate supply of P, K, and other deficient secondary and micronutrients is essential (Tiwari, 2002; Dobermann et. al., 2004).

Conclusion

Considering 50% of the increase in productivity on farmers' fields as compared to the increases observed in these on-station experiments, and only 25% area coverage with SSNM, the total annual increase in RWCS production could be 11 M t for rice and 4.75 M t for wheat. Site- and crop-specific balanced fertilisation in addition to maintaining food security will help sustain soil and environment health due to improved nutrient use efficiency. BC-INDIA

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

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

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

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

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

Researcher at rainfed rice plots.

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

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

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

The average two season grain and straw yield of rice (Cv. Khitish) varied from 2,010 to 3,990 kg/ha and 4,760 to 8,000 kg/ha, respectively (**Table 1**). Maximum grain yield of rice was obtained at 125% of the optimum application rate. The straw yield was also highest in this treatment, followed closely by the 100% nutrient application. Omission of nutrients from the optimum treatment caused yield losses that varied between 20 to 35% (**Table 1**). Yield was strongly influenced by exclusion of Zn, B, and P that caused comparable yield losses (34%). Yield loss was much higher with omission of nutrients from the 125% OPT treatment and varied between 15 to 50%. Yield loss was highest in the OPT-P plot (50%), followed by more than 30% yield losses due to exclusion of Zn, K, and B from the OPT treatment. The yield data revealed that P, Zn, and B are the main limiting factors under the present experimental set up. Exclusion of nutrients from the optimum treatment did not influence the harvest index (**Table 1**).

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

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

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

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

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

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

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

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

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

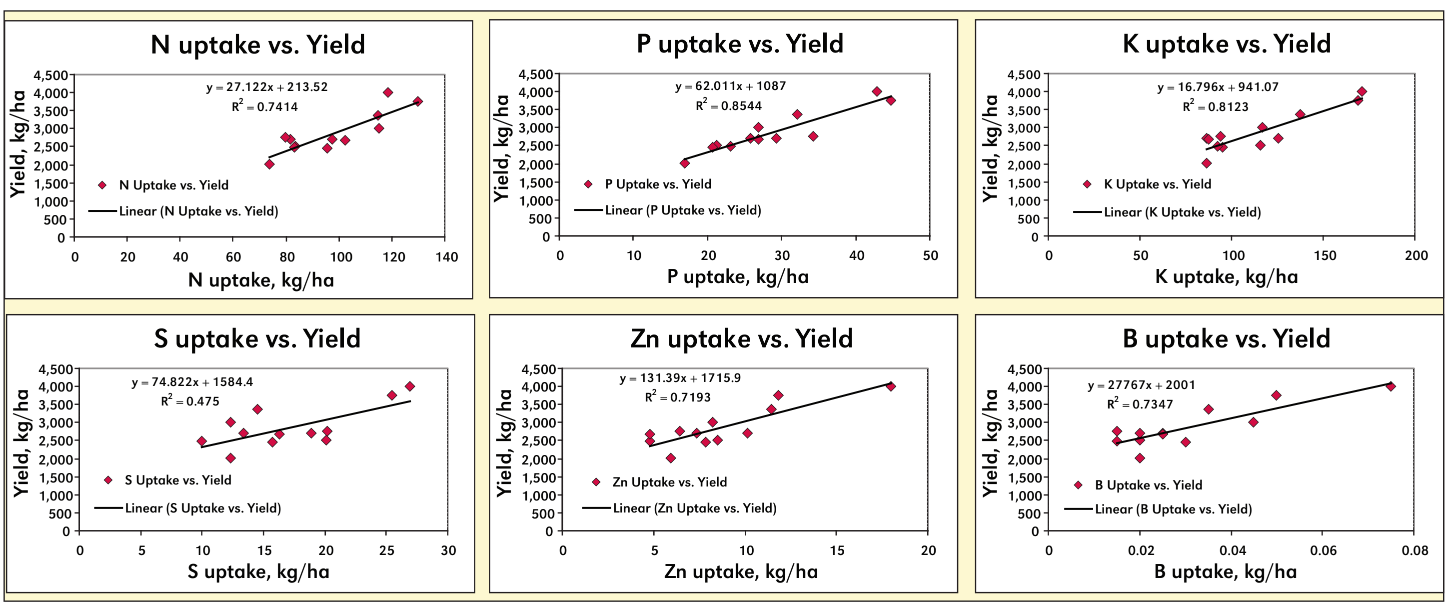

Figure 1. Interrelation between grain yield and uptake of nutrients in IET 1444, Pundibari, West Bengal.

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

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

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

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IPI-OUAT-IPNI International Symposium on Potassium Role and Benefits in Improving Nutrient Management for Food Production, Quality and Reduced Environmental Damage

November 5 -7, 2009, Orissa University of Agriculture and Technology (OUAT), Bhubaneswar, Orissa

Co-sponsors: Indian Council of Agricultural Research (ICAR), Fertiliser Association of India (FAI), Bangladesh Fertiliser Association (BFA), Pakistan Agricultural Research Council.

The symposium main themes are:

- Nutrient management to meet challenges of food security
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- The role of extension in increasing agricultural productivity
- Potassium and the environment
- Nutrient mining and input output balances

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Soil Test-Based Nutrient Management to Attain Targeted Yields in a Rice-Based Cropping Sequence

By Supratik Ghosh, Sourov Chatterjee, and S.K Sanyal

A 2-year experiment was conducted in the alluvial tract of West Bengal to study appropriate P and K management strategies in a jute-kharif (winter) rice-boro (summer) rice sequence under a lowland rice ecosystem. Compared to State recommended rates, the approach based on soil testing did lead to higher crop yields, net returns, and relative agronomic effectiveness.

India's resounding success from its past green revolution has been followed by stagnating or declining agricultural productivity, even with increased total fertiliser use in the country over the years. This declining factor productivity is largely due to imbalanced fertiliser use (Kumar et. al. 2007). Fertiliser application is highly skewed in favour of N, with relatively small use of K and P application, and rare use of secondary and micronutrients.

Current generalised fertiliser recommendations are also sub-optimal and need upward refinement. In rice-based cropping systems, a negative K balance of 31 kg K_2O/ha/year was estimated, and this imbalance is projected to increase further (Trivedi, 2001). Phosphorus removal under this intensive crop rotation amounts to 150 kg P_2O_5/ha/year, which is often higher than the annual nutrient replenishment (Tandon and Sekhon, 1998). Keeping in view the need for more balanced and intensive agriculture in India, P and K application needs to be increased (Sanyal and Chatterjee, 2007). The present study was conducted to optimise P and K management strategies to achieve maximum yields in an important rice-based cropping sequence.

Two years of field experiments were conducted on a jute (var. JRO-524)-*kharif* rice (var. IET-4786)-*boro* rice (var. IET-4094) sequence at Kalyani, West Bengal, India. The experiment was laid out in randomised block design with nine treatments. The treatments included: (i) a control (C), (ii) a soil test-based recommendation of N_x, P_y, and K_z, where x, y, and z represent kg/ha rates for a given targeted yield, (iii) the State recommended doses of N_s, P_s, and K_s (**Table 1**), and (iv) several other treatments having gradual withdrawal of P and K from the full soil test-based treatment. Deficient micronutrients were applied only in the first year of experimentation. Soil samples were collected at the initial stage and were analysed for physiochemical properties as well as for pools of different forms and/or fractions of soil P and K. Soil at the site was an Entisol with clay loam texture, a pH of 8.0, and 0.4% organic C, and a CEC of 12 cmol/kg. Available P and K status was 45 kg P_2O_5/ha and 162 kg K_2O/ha.

Water soluble K of the experimental soil was low [0.05 cmol/kg], whereas the non-exchangeable K (NEK) [6.02 cmol/kg] and the total K [52.2 cmol/kg] were much higher (**Table 2**). From this data, the site was expected to release significant amounts of K from the native pool under plant uptake driven stress. The release pattern of NEK under successive extraction under boiling 1M HNO_3 is presented in **Table 2**, which also corroborated the inference above regarding a substantial reserve of non-exchangeable K in the soil. Constant-rate K (CR-K) of the soils was determined by successive extraction of the soil with boiling 1 M HNO_3 to a stage where release of K from the soil continued at a more or less constant rate. In the Kalyani soil, CR-K was reached after the fourth extraction. By subtracting the amount of CR-K from K released in each step of successive extraction, the amount of relatively easily extractable or available form of nonexchangeable K was computed. This latter form is known as Step-K.

The different fractions of soil P at the experimental site, determined by analytical method of Chang and Jackson (1957), are shown in **Table 3**. The distribution of inorganic P fractions followed the order: Ca-P > Fe-P > reductant soluble P > Al-P > occluded Al-P. A high content of Ca-P is likely a result of a high content of exchangeable Ca (9.10 cmol/kg) and the calcareous nature of the soil, and this fraction is relatively easily

Table 1. Outline of state recommendations and soil test-based recommendations used in this study.

	State recommendations, kg/ha			Soil test-based recommendations, kg/ha				
	Ns	P[1]s	K[1]s	Nx	Py	Kz	S	B
Jute	50	25	50	200	50	100	30	1.5
Kharif rice	60	30	30	168	56	100		
Boro rice	100	50	50	168	56	140		

[1]P_2O_5 and K_2O

Table 2. Contents of different forms and fractions of K in the initial soil at Kalyani.

	Forms of K [cmol/kg]								
Site	Water soluble K	Exchangeable K		Non-exchangeable K		Mineral K		Total K	
Kalyani	0.05	0.08		6.02		46.0		52.2	
	(NEK - CR-K) in successive extractions [cmol/kg]							Step-K[1]	CR-K[2]
	I	II	III	IV	V	VI	VII	[cmol/kg]	
	5.04	2.12	0.24	0.05	-	-	-	7.45	0.29

[1]Step-K relatively easily extractable or available form of nonexchangeable K.
[2]CR-K, Constant-rate K, relatively stable form of nonexchangeable K.

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

Table 3. Content of plant available P and different P fractions in the initial soil at Kalyani.

Site	Available P, kg/ha	Content of different P fractions, mg/kg				
		Al-P	Fe-P	Ca-P	Reductant soluble Fe-P	Occluded Al-P
Kalyani	44.8	6.32	19.2	28.0	15.2	1.60

Table 4. Effect of different treatments on yield (fibre and stick) of jute at Kalyani.

	1st year		2nd year	
	Yield, t/ha		Yield, t/ha	
Treatments	Fibre	Stick	Fibre	Stick
$T_1 (N_x, P_y, K_z)$	2.90	6.00	2.86	6.06
$T_2 (N_s, P_y, K_z)$	2.70	5.40	2.66	5.83
$T_3 (N_s, P_{0.5y}, K_z)$	2.70	5.10	2.40	5.60
$T_4 (N_s, P_{0.25y}, K_z)$	2.74	4.90	2.20	5.30
$T_5 (N_s, P_o, K_z)$	2.58	5.00	2.03	5.03
$T_6 (N_s, P_y, K_{0.5z})$	2.52	4.10	2.36	5.50
$T_7 N_s, P_y, K_{0.25z})$	2.43	4.10	2.30	5.26
$T_8 (N_s, P_y, K_o)$	2.45	4.30	1.96	5.00
$T_9 (N_s, P_s, K_s)$	2.53	4.70	2.40	5.26
$C (N_0, P_0, K_0)$	1.90	3.60	1.63	4.53
S.Em (±)	0.13	0.22	0.08	0.10
C.D. (P=0.05)	0.40	0.68	0.23	0.24

available as compared to occluded P.

Application of fertilisers based on soil test (T_1) led to highest fibre yields of jute (**Table 4**). Gradual reduction of applied P and K (i.e., T_3, T_4, T_5 for P; and T_6, T_7, T_8 for K) led to significant declines in fibre yield. These yield declines were generally more prominent under the withdrawal of K fertiliser. Yield responses to increasing K application are reported by Mitra et al. (1999) and Roy and Chouddhury (2000). A similar trend was observed for stick yield of jute.

Grain and straw yield of *kharif* rice was significantly influenced by P and K application. However, responses were not apparent in the first year of experimentation due to significant water stress suffered by this rainfed crop (**Table 5**). Differences between the performance of T_1 and T_9 (the State recommendation) were significant during the second year of experimentation. Gradual reduction in P and K application led to lower grain yields, but yield losses were even more prominent under lower K rates. This response was attributed to low initial plant available K as well as a high K-fixing capacity of this illite-dominated soil. Poor response of *kharif* rice to P application could be attributed to the mobilisation of fixed soil P under submerged lowland conditions, and also the relatively high available P status after the harvest of jute in the second year (data not shown). Rice straw yields followed a pattern which was similar to the corresponding grain yields (**Table 5**).

Grain yield of *boro* rice followed similar trends as those obtained with the *kharif* rice. However, yields were generally higher compared to those obtained in the *kharif* season. *Boro* rice showed a much better response to applied P and K compared to the *kharif* crop due to less control over the growing environment in the rainfed rice season. In the two *boro* season crops, the response to applied P varied between 0.4 to 1.0 t/ha while K application improved yield by 1.1 to 1.5 t/ha compared to the plots without K.

Economics of Crop Production

During the first year, the highest net profit from jute was obtained under T_9, while T_1 returned the highest net profit in the second year (**Table 6**). For *kharif* rice (IET-4786) the first year brought negative net returns due to very low yields and production expenses exceeding gross returns. During the

Table 5. Effect of different treatments on yield (grain and straw) of *kharif* and *boro* rice.

	Kharif rice (var. IET-4786)				*Boro* rice (var. IET-4094)			
	1st Year		2nd Year		1st Year		2nd Year	
	Yield, t/ha		Yield, t/ha		Yield, t/ha		Yield, t/ha	
Treatment	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
T_1	1.88	2.71	3.93	4.93	5.45	6.10	5.79	6.18
T_2	1.75	2.57	3.72	4.70	5.32	5.84	5.51	6.09
T_3	1.72	2.49	3.53	4.30	5.12	5.60	5.32	5.78
T_4	1.67	2.49	3.34	4.06	5.17	5.39	5.24	5.57
T_5	1.66	2.41	3.14	3.93	5.08	5.47	4.81	5.24
T_6	1.76	2.61	3.26	4.06	5.06	5.61	4.98	5.42
T_7	1.66	2.37	2.90	3.60	4.75	5.22	4.54	5.24
T_8	1.45	2.39	2.72	3.63	4.34	5.06	4.25	4.79
T_9	1.76	2.37	3.23	3.96	4.79	5.12	4.51	5.07
C	1.04	2.17	2.16	3.09	3.03	3.87	2.98	3.92
S.Em (±)	0.08	0.58	0.09	0.12	0.14	0.22	0.07	0.08
C.D. (P=0.05)	0.24	NS	0.27	0.37	0.42	0.67	0.22	0.26

Table 6. Economics of crop production for different treatments at Kalyani.

	1st year			2nd year		
	Net return, Rs./ha			Net return, Rs./ha		
Treatment	Jute (JRO-524)	*Kharif* rice (IET-4786)	*Boro* rice (IET-4094)	Jute (JRO-524)	*Kharif* rice (IET-4786)	*Boro* rice (IET-4094)
T_1	5,870	-1,870	16,770	14,880	11,890	19,520
T_2	5,560	-1,260	16,520	14,720	11,550	18,550
T_3	7,800	-1,740	15,720	12,800	10,720	17,730
T_4	9,110	-1,760	16,360	11,500	9,690	17,350
T_5	9,010	-1,590	15,910	10,450	8,680	14,900
T_6	4,510	-1,420	15,370	12,540	8,940	15,310
T_7	4,320	-1,900	13,540	12,050	6,60	12,860
T_8	5,140	0	11,250	9,440	5,980	10,990
T_9	13,270	-340	15,150	13,240	9,530	13,400
C	4,970	-3,350	6,210	8,160	3,970	6,080

Price details used in economic analysis: *kharif* and *boro* rice: Rs. 5.50 per kg; Jute: Rs. 8.60 per kg; N: Rs.10.50 per kg; P_2O_5: Rs. 16.22 per kg; K_2O: Rs. 7.43 per kg.

second year the highest net return in *kharif* rice was obtained with T_1. Net return for *boro* rice in both years was highest under T_1.

The Relative Agronomic Effectiveness (RAE), expressed as percent, was calculated for each crop using **Equation 1**. Using the State recommended doses (T_9) as the standard treatment, for all crops, the highest RAE value was obtained with T_1 (**Figure 1**). The gradual reduction of applied P (T_3 to T_5) and K (T_6 to T_8) from the soil test recommendation led to declining RAE. As in grain yield of rice, or fibre yield of the jute, the decline in RAE was more sensitive to the decrease in application rate of K than P.

In general, application of nutrients following soil test-based

Equation 1:

$$\text{RAE} = \frac{\text{Yield in treatment} - \text{Yield in control}}{\text{Yield in state recommendation} - \text{Yield in control}} \times 100$$

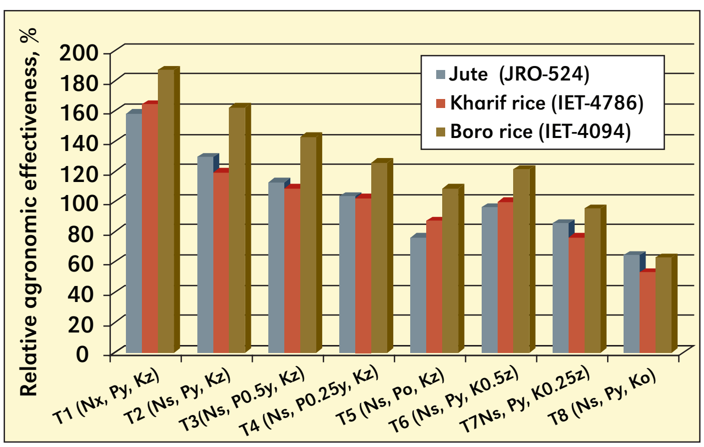

Figure 1. Relative Agronomic Effectiveness (%) of different levels of P and K fertilization in Jute and Rice at Kalyani.

recommendation led to significantly higher yield of each crop under lowland ecosystem than those where nutrients were applied following general recommendations. The experiment showed that soil K is more limiting to crop growth as compared to P in this alluvial soil. This study also shows that a nutrient management strategy based on soil test can improve the productivity of the Jute-Rice-Rice cropping system, one of the important cropping sequences followed in West Bengal. This also provides an opportunity for higher economic return to farmers. BC-INDIA

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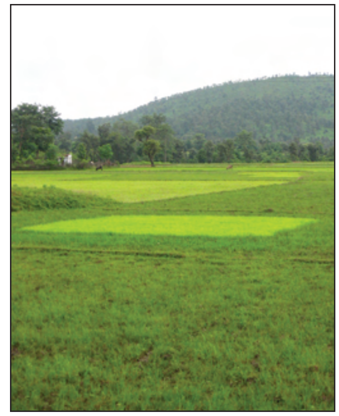
Site-Specific Nutrient Management Performance in a Rice-Wheat Cropping System

By Harmandeep S. Khurana, Bijay-Singh, Achim Dobermann, Steven B. Phillips, Ajmer S. Sidhu, and Yadvinder-Singh



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

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

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

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

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

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

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

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

- Recovery efficiency of fertiliser N (REN) is the increase in plant N uptake per unit fertiliser N applied (kg plant N/kg fertiliser N).
- Physiological N efficiency (PEN) is the increase in grain per unit increase in plant N uptake from fertiliser (kg

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

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

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

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

grain/kg plant N).

- Agronomic N use efficiency (AEN) is the product of REN and PEN, expressed as the yield increase per unit fertiliser N applied (kg grain yield/kg fertiliser N).
- Gross return over fertiliser costs (Rs/ha/crop) is calculated as revenue (grain yield x farm gate paddy and wheat prices) minus fertiliser cost.

Compared with FFP, SSNM significantly increased grain yield in all regions in the two wheat and rice crops (**Figure 1**). But there was no significant difference between the 2 years of experimentation, which helped us pool the year-wise data for grain yield for each region. On average, SSNM generated a yield gain of at least 0.9 (17%) and 0.5 t/ha (12%) in rice and wheat crops, respectively, compared with FFP in approximately 48% of the sites studied. At 21 of the total 56 farms studied, rice grain yield increases were ≥1 t/ha with SSNM compared with FFP, while at 24 of the total 56 farms studied, wheat grain yield increases were ≥0.8 t/ha, showing the potential of the SSNM approach used. Another interesting fact observed was that the maximum increases in rice and wheat grain yields were obtained at sites with low fertility soils, while the regions with high fertility soils had minimum but significant increases in grain yields of rice and wheat crops.

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

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

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

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

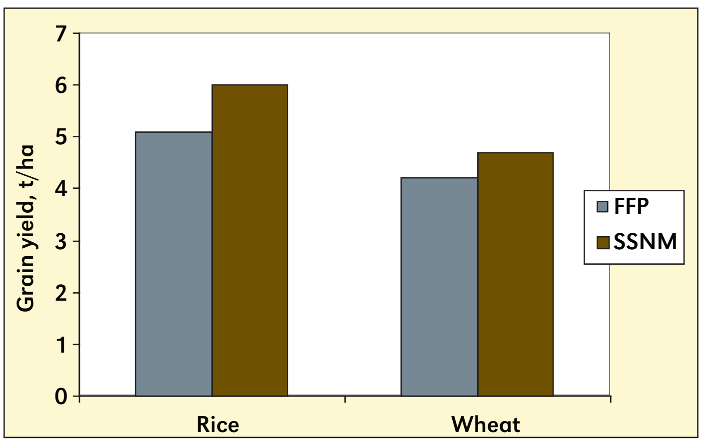


Figure 1. Grain yield of rice and wheat crops in FFP and SSNM averaged for 2 years.

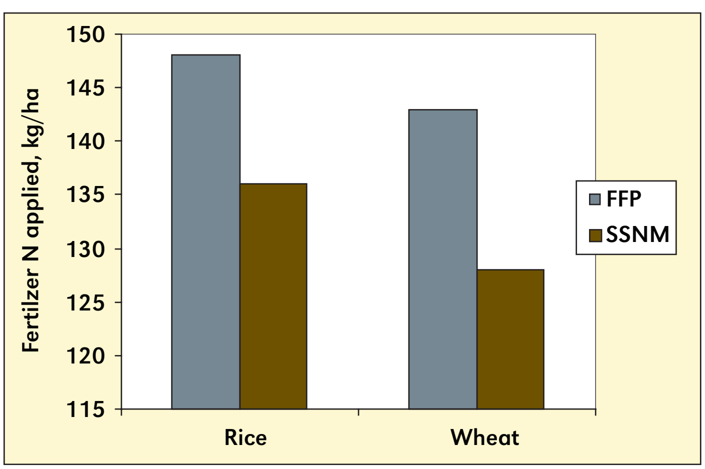


Figure 2. Fertiliser N applied to rice and wheat crops in FFP and SSNM averaged for 2 years.

This corroborates our hypothesis that blanket fertiliser recommendations, as is the current norm in Punjab, are of limited use in tackling site-specific soil fertility problems and that the adoption of site-specific strategies can give some impetus to the productivity growth of rice and wheat crops.

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

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

Significant increases in N use efficiency were achieved in rice and wheat through the field-specific N management practiced in the SSNM treatment (**Figure 3**). In general, compared with the FFP, less fertiliser N was applied (**Figure 2**), and AEN, REN, and PEN were significantly increased with SSNM. On average, AEN was increased by 7.3 kg/kg (83%)

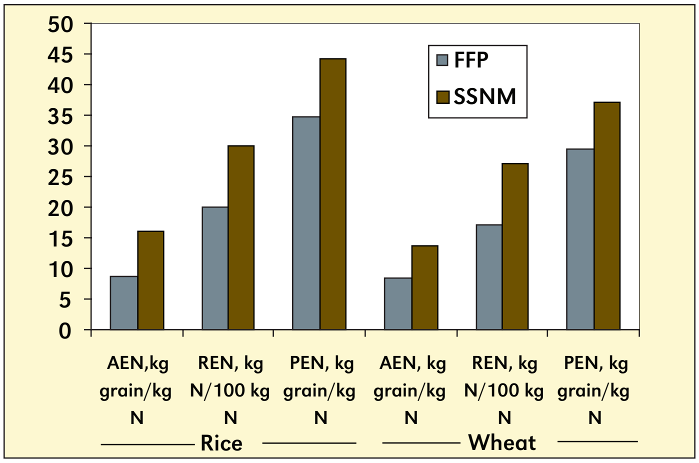


Figure 3. Fertiliser N use efficiencies in rice and wheat crops in FFP and SSNM averaged for 2 years.

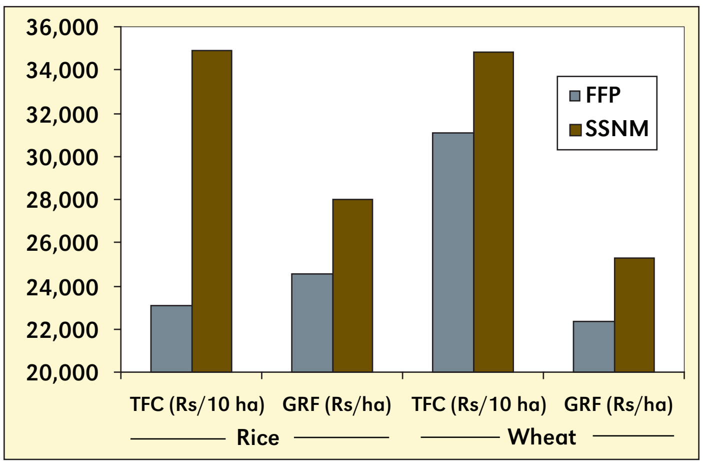


Figure 4. Total fertiliser cost (TFC) and gross returns above fertiliser cost (GRF, profitability) in rice and wheat crops in FFP and SSNM averaged for 2 years. (Prices used were: N fertiliser Rs.13.92 per kg N; P fertiliser Rs.78.73 per kg P; K fertiliser Rs.21.75 per kg K; price of wheat grain Rs.6.09 per kg; and price of paddy Rs.5.22 per kg.)

and 5.3 kg/kg (63%), REN by 0.10 kg/kg (50%) and 0.10 kg/kg (59%), and PEN by 9.5 kg/kg (27%) and 7.7 kg/kg (26%) in rice and wheat crops, respectively. This increase was attributed to more uniform N applications among sites under SSNM as compared to under FFP. Also, the N applications were spread more evenly through the growing season and avoided heavy single applications at early growth stages of rice and wheat crops when compared with FFP.

Site-specific nutrient management led to a small increase in the average fertiliser cost (Rs.370/ha/crop [12%] in wheat and Rs.1,190/ha/crop [52%] in rice), but comparatively a larger increase in gross returns over fertiliser (GRF) (Rs.2,950/ha/crop [13%] in wheat and Rs.3,450/ha/crop [14%] in rice) compared with FFP (**Figure 4**). Increase in the average fertiliser cost under SSNM was mainly attributed to an increase in K fertiliser use – an important input from the balanced crop nutrition point of view, but one that is generally skipped by farmers in Punjab.

Conclusions

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

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Phosphate Fertiliser Management of Hybrid Rice

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

Appropriate P application rates were suggested for rice through a soil test-based approach wherein application of the full recommendation was responsible for a 5.2 t/ha grain yield response which raised the potential of a two crop system to 13.9 t/ha. The soil test-based approach improved harvest index, increased the recovery efficiency of N and K, and the corresponding economic benefits from hybrid rice cultivation.

Proper P nutrition is critical for producing maximum rice yields, which contributes about 84% of the total food grains grown in the state of Orissa. It promotes vigorous, early plant growth and development with strong root systems and profuse tillering, in addition to flowering, fruiting, and many other biochemical processes in the plant. However, its deficiency in rice is often referred to as a "hidden hunger" because its symptoms are hard to observe unless deficient plants are directly compared to sufficient plants (Dunn and Stevens, 2007).

The soils of Orissa are largely acidic (70%) in nature and low to medium in available P status. The red and lateritic soils have particularly low soil P status (Bray-1 P, 6 to 27 kg/ha), although their total P_2O_5 content, is considered adequate (0.08 to 0.35%). The extent of P fixation is up to 92% under well aerated acid soil conditions and up to 70% under reduced/submerged condition (Pattanayak and Misra, 1989). Recovery of applied P seldom exceeds 25% in the year of application (Misra and Pattanayak, 1997) and its proper management under acid soil conditions is very critical for improving production. The average N + P_2O_5 + K_2O consumption of Orissa is about 50 kg/ha, of which P_2O_5 contributes about 12 kg/ha. Such low application of nutrients, coupled with high P-fixing soils, is a major contributing factor for low crop productivity in the state.

High yielding rice varieties, including hybrids, have been introduced in Orissa to increase food grain productivity. The nutrient requirement of hybrid rice is high, but most often fertiliser is recommended without evaluating soil nutrient status or the yield potential of hybrid rice. The result is inadequate and unbalanced fertilisation leading to poor yields that are much lower than expected achievable yield. Nutrient mining or accumulation and increased potential for environmental pollution are other impacts of such fertilisation practice. The present study was undertaken to evaluate the effect of a soil test-based fertiliser recommendation and graded doses of P on hybrid rice yield, nutrient uptake and recovery, and post harvest soil properties.

The field experiment was conducted at the Central Farm of Orissa University of Agriculture and Technology (Agro Ecological Region-12) for two consecutive seasons, namely the winter and summer rice seasons of 2005-06. The soil at the site was an Inceptisol with sandy texture and an acidic pH (pH 5.0). The surface (0 to 15 cm) soil was analyzed according to the Agro Services International (ASI) analytical method (Portch and Hunter, 2002). The hybrid rice crop (cv. Sreeram) received 12 treatments, each replicated three times in a randomised block design. The ASI recommended dose of fertiliser for rice (for two seasons) was 290 kg N, 170 kg P_2O_5, 180 kg K_2O, 1 kg B, 7 kg Zn, and 4 kg Cu/ha. This paper considers seven treatments including a control, five treatments with P application rates from 0 to 100% of the ASI recommendation in increments of 25%, and a dose having 1.5 times the ASI recommended rates for N, P_2O_5, and K_2O (**Table 1**).

A blanket dose of 5 t FYM/ha and 1,800 kg $CaCO_3$/ha was applied to all treatment except the control. Basal application to 20 day-old transplants included 25% of total N and K rates, 50% of the total P, and all of the B, Zn, and Cu. The crop was topdressed at 21 days after transplanting with 50% of the total N, P, and K rates. The remaining 25% N and K was applied at the boot leaf stage.

Uniform cultural and irrigation practices were followed for all treatments. The crop was harvested 120 days after sowing and grain, straw, and chaff yields (sun-dried) were recorded. Two border rows were left in each treatment plot for analysis of plant nutrient concentration and uptake. Grain, straw, and chaff samples were analysed for nutrient concentration and uptake at maturity following standard procedures.

Under the selected range of treatments, cumulative yield of grain, straw, and chaff ranged between 4.9 to 13.9 t/ha, 6.7 to 14.6 t/ha, 0.48 to 0.95 t/ha, respectively (**Table 1**). Excluding P entirely from the fertiliser schedule resulted in 38% less yield. Straw yields followed a similar trend to that observed for grain. Chaff production was lowest under the ASI recommendation and it increased steadily to 0.95 t/ha under complete omission of P. Harvest index (HI = grain yield/total biomass)

Table 1. Influence of incremental doses of P on yields, harvest index, and biomass ratios of hybrid rice, Orissa University of Agriculture.

	Yield, t/ha			Harvest	Grain:	Grain:
	Grain	Straw	Chaff	index	straw ratio	chaff ratio
Control	4.9	6.7	0.5	0.4	1.37	10
ASI-P	8.7	12.8	0.95	0.38	1.47	9
ASI+25% P	9.7	13.2	0.9	0.4	1.39	11
ASI+50% P	11.7	13.4	0.82	0.45	1.15	14
ASI+75% P	12.9	14.0	0.68	0.48	1.09	19
ASI+100% P	13.9	14.0	0.48	0.5	1.01	29
150% NPK	9.0	14.6	0.79	0.37	1.62	11
C.D.† (p=0.05)	0.47	0.64	0.06	–	–	–

†Denotes the critical difference

Abbreviations and notes for this article: N = nitrogen; P = phosphorus; K = potassium; B = boron; Zn = zinc; Cu = copper; FYM = farmyard manure; CD = critical difference.

Table 2. Influence of incremental dose of P with full dose of N, K, and other nutrients on nutrient uptake and apparent recovery by hybrid rice, Orissa University of Agriculture.

	Nutrient uptake, kg/ha					Recovery efficiency, %		
Treatment	N	P	K	S	Ca	N	P	K
Absolute control	83.0	15.0	148.0	12.0	28.0	-	-	-
ASI-P	191.0	20.7	248.0	15.0	36.0	37	-	67
ASI + 25 % P	207.0	28.2	293.0	17.0	46.0	43	70	97
ASI + 50 % P	212.0	33.8	307.0	21.0	53.0	45	50	106
ASI + 75 % P	224.0	36.7	346.0	30.0	59.0	48	39	132
ASI + 100 % P	236.0	40.0	359.0	27.0	63.0	53	38	141
150 % NPK	224.0	37.0	355.0	27.0	60.0	32	22	92
CD (P = 0.05)	3.5	1.8	20.0	31.0	3.2	-	-	-

was again highest under the ASI recommendation, and HI decreased steadily to a minimum due to gradual withdrawal of P application (**Table 1**). The narrowest grain: straw ratio was recorded with the ASI recommended P dose and this ratio widened as P rate decreased. The grain: chaff ratio varied from an undesirable 9:1 under P omission to a desirable 29:1 under the ASI recommendation. Application of macronutrients at 150% of the ASI recommended rates produced more straw and chaff, and less grain than the 100% recommendation, which lead to a wider grain: straw ratio, a narrow grain: chaff ratio, lowest harvest index, and showed no added advantage.

Data on nutrient uptake and apparent nutrient recovery are presented in **Table 2**. Nutrient uptake by rice could be arranged as follows: K > N > P. Higher P application rates increased uptake of all nutrients – a relationship which held true up to and including the P rate provided under the ASI recommendation. Maximum nutrient removal occurred under the ASI recommendation. By comparison, nutrient uptake under the 1.5 ASI treatment appeared to plateau or decrease slightly.

Without P application, the apparent recoveries for N and K amounted to 37% and 67%, respectively. Increasing P application in 25% increments increased N and K recoveries considerably to a maximum of 53% for N and 141% for K at the ASI P recommendation. Incremental rates of P caused a steady decline in P recovery. Phosphorus recovery ranged between 70% under the lowest application rate to 38% and 22% under the ASI and 1.5 ASI recommendations, respectively.

Partial factor productivity (PFP) of nutrients in this experiment was estimated by dividing grain output by the quantity of a single nutrient. The results showed that PFP of N, K, Zn, B, and Cu steadily improved with incremental P rates up to the recommended level. Any further increase in P rates decreased grain output per unit of nutrient (**Figure 1**). Declining PFP in crop production is a major concern in India and the current experiment showed that balanced and adequate nutrition can reverse the situation.

The cumulative two-season production cost of hybrid rice (**Table 3**) varied between Rs.35,302/ha to Rs.67,676/ha. Highest income (Rs.128,303) and profit (Rs.62,497) per ha was obtained in the full recommended dose of nutrient application. The return per rupee invested varied from 1.29 to 1.95 and highest return was in the ASI + 100% P dose. There was no extra economic advantage of application of 150% of the recommended rates of nutrients.

Table 3. Economics of hybrid rice cultivation, Orissa University of Agriculture.

Treatments	Production cost, Rs./ha	Income, Rs./ha	Benefit, Rs./ha	Income per Rs. investment
Absolute control	35,302	46,553	11,251	1 : 1.32
ASI-P	62,066	83,323	21,257	1 : 1.34
ASI + 25 % P	63,001	90,143	27,142	1 : 1.43
ASI + 50 % P	63,936	109,208	45,272	1 : 1.71
ASI + 75 % P	64,871	119,828	54,957	1 : 1.85
ASI + 100 % P	65,806	128,303	62,497	1 : 1.95
150 % NPK	67,676	87,228	19,552	1 : 1.29

*Costs assumed for this example: hybrid fine rice, Rs.8,500/tonne; N, Rs. 11/kg; P_2O_5, Rs.22/kg; K_2O, Rs.8/kg; borax, Rs. 90/kg; zinc sulphate, Rs. 55/kg; and copper sulphate, Rs.160/kg.

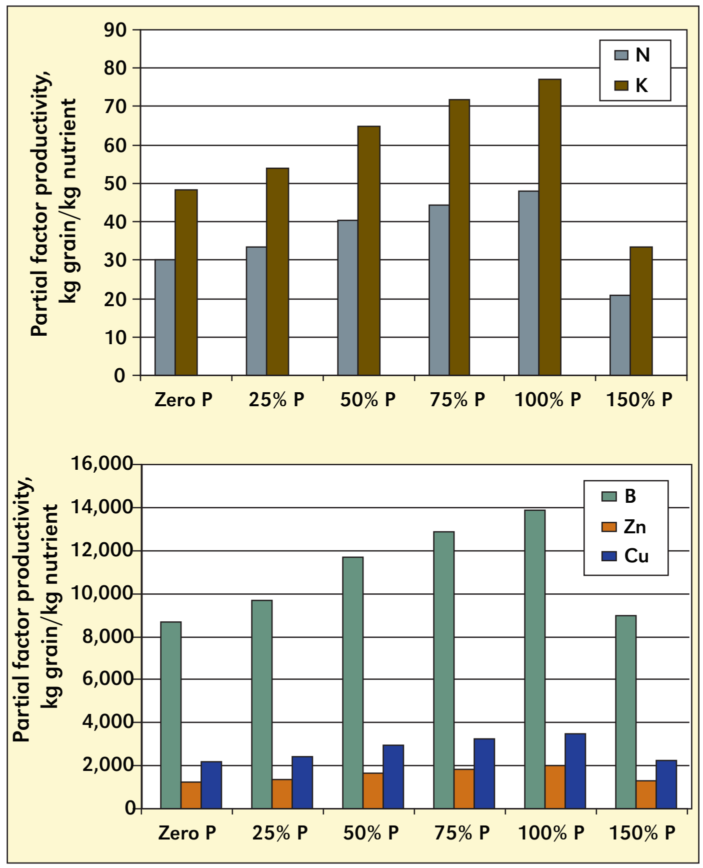

Figure 1. Effect of P rate on partial factor productivity for N and K (top) and for B, Zn, and Cu (bottom), Orissa University of Agriculture.

Summary

Productivity of rice in India, particularly in the eastern part, has stagnated over the past few years. The ever-increasing population in the country demands that rice productivity is also improved. Hybrid rice, with improved yield potentials as compared to the existing varieties, will play an important role

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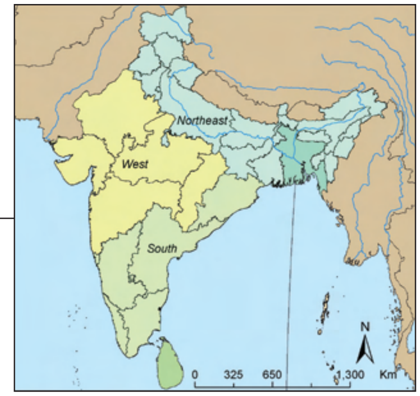

The engine that drives the educational programs of IPNI is scientific research. Here is a listing of the current research being funded within India. More details on these projects can be obtained from India Programme staff or from the research database on the website: http://www.ipni.net/research.

Northeast Zone	Project Number	Title
	EZ INDIA-40	Balanced Fertiliser Use in Major Crops of Jharkhand
	EZ INDIA-41	Maximising Productivity, Farmer Profit, and Nutrient Use Efficiency in Rice-Based Cropping Systems in the Terai Agro-Ecological Region of West Bengal
	EZ INDIA-42	Site-Specific Potassium Management for Sustainable Production in Selected Rice Domains of West Bengal
	EZ INDIA-43	Importance of Soil Test Based Nutrient Application through Farmers' Participatory Approach in Red and Lateritic Soils of West Bengal
	EZ INDIA-45	Spatial Variability in Soil Physico-Chemical Properties and Nutrient Status in an Intensively Cultivated Village of West Bengal
	EZ INDIA-46	Site-Specific Nutrient Management in Wheat in East India
	NWZ INDIA-59	Balanced Fertilisation for Quality Fruit (Mango) Production in Uttar Pradesh
	NWZ INDIA-63	Site Specific Nutrient Management for High Yield and High Profits in the Southwestern Plain Zone of Uttar Pradesh
	NWZ INDIA-69	Maximising Crop Yield through Site-Specific Nutrient Management in Uttar Pradesh
	NWZ INDIA-73	Evaluating Production Systems for Attaining Maximum Productivity and Profits in Uttar Pradesh

West Zone	Project Number	Title
	NWZ INDIA-64	Site-Specific Nutrient Management for Maximum Economic Yield and Quality of Sugarcane in Maharashtra
	NWZ INDIA-70	Site-Specific Nutrient Management in Mosambi Sweet Orange
	NWZ INDIA-71	Balanced Fertilization for Maximisation of Crop Yields in Gujarat
	NWZ INDIA-72	Appraisal of Multi-Nutrient Deficiencies and Their Redressal through Site-Specific Nutrient Management

South Zone	Project Number	Title
	SZ INDIA-47	Investigations on Balanced Fertilization for Breaking Maize Yield Barriers in Tamil Nadu
	SZ INDIA-48	Balanced Fertilisation for the Maize-Redgram Cropping Sequence in Alfisols of Karnataka
	SZ INDIA-49	Site-Specific Nutrient Management for Maximisation of Crop Productivity in Southern Karnataka
	SZ INDIA-50	Site-Specific Nutrient Management for Maximum Economic Yield and Quality of Transgenic Cotton in Northern Karnataka

The IPNI India Programme regional zones are staffed by Dr. K. Majumdar (North and East Zones and Bangladesh), Dr. H. Singh Khurana (West Zone), and Dr. T. Satyanarayana (South Zone and Sri Lanka). BC-INDIA

in maintaining food security. However, we need to keep in mind that the full potential of hybrid rice can only be harnessed with appropriate management, particularly nutrient management. One of the major reasons for falling partial factor productivity in the country is inadequate and imbalanced nutrient application. This experiment clearly showed that soil test-based nutrient application, with focus on adequate application of all limiting nutrients following the concept of site-specific nutrient management, will help to break existing yield barriers. This will also ensure higher nutrient use efficiency and better economics of production, which are prerequisites of a sustainable production system. BC-INDIA

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AN AWAKENING TO THE VALUE OF FERTILIZERS IN FOOD PRODUCTION

Greetings and welcome to the second issue of BETTER CROPS-INDIA. We were very happy with the response we received to the first issue of this publication in 2007 and look forward to future issues.

The year 2008 has brought profound changes to the fertilizer industry around the world. The sudden increase in fertilizer demand from all regions has resulted in a short supply and rising fertilizer prices. Indian farmers have been protected from these changes to some degree. However, government agencies supporting fertilizer subsidies have felt the pressure of not only rising fertilizer costs, but also increasing cost of food grain commodities.

During this past year we have read many headlines about not only the cost, but the value of fertilizers to food supplies. While all of us in this industry are well aware of the need for nutrient replacement in most agricultural soils, the recent renewed interest in the fact that 40 to 50% of all food comes from the use of fertilizer nutrients has been high on the agenda of public policy makers and the general public. Fertilizers are critical to staving off hunger in many parts of the world, and the fact that we can continue to improve the yield and quality of food products with balanced fertilizer use, is an important role for the agricultural community in our society. And profits…well fertilizers also play a major role in enhancing farmer profits and supporting rural economies.

On a global scale, food grain stocks continue to decline…a serious problem for all countries to contend with. Our research activities in IPNI have clearly provided us with the knowledge that in most countries we can make significant improvements in food grain production with the advancement of existing technologies. Improved crop varieties, cultural practices and fertilizer nutrients all have a role to play in meeting the growing demand for food. We in IPNI are very proud of the past efforts of our employees in India, helping to demonstrate the positive role that plant nutrients play in building on the agricultural production in the country.

We prepare to begin 2009 with a renewed optimism in agriculture, a number of new staff in IPNI, and an ongoing commitment to maintain our focus on the positive role that fertilizers can play in food security for India.

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BETTER CROPS–INDIA

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