BETTER CROPS–INDIA

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Soil System-Based Approach – A Tool for Fish Pond Fertilisation

In This Issue...

Nutrient Management to Improve Maize Productivity

Zinc-Enriched Urea Boosts Rice Grain Yield and Quality

On-Farm Evaluation of SSNM in Pearlmillet-Based Systems

...and much more

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Our cover: Fish pond harvest near Jhargram of West Midnapore District, West Bengal, India.

Photo by Dr. Kaushik Majumdar

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2009 IPNI Scholar Award Recipients Announced

The 2009 winners of the Scholar Award sponsored by the International Plant Nutrition Institute (IPNI) have been selected. The awards of US$2,000 (two thousand dollars) are available to graduate students in sciences relevant to plant nutrition and management of crop nutrients. The winners from India are **Govindaraj Mahalingam** and **Ramesh Thangavel**.

"There were many highly qualified applicants this year from a wide array of universities and fields of study," said Dr. Terry L. Roberts, IPNI President. "The academic institutions these young people represent and their advisers and professors can be proud of their accomplishments. The selection committee adheres to rigorous criterion evaluating important aspects of each applicant's academic achievements." In total, 14 (fourteen) graduate students were named to receive the IPNI Scholar Award in 2009, with the most widespread geographic distribution ever for the awards.


Govindaraj Mahalingam

Mr. Govindaraj Mahalingam began his Ph.D. program in 2007 in Plant Breeding and Genetics at Tamil Nadu Agricultural University, Coimbatore, India. His dissertation title is "Genetics of Grain Iron and Zinc Content in Pearl Millet" and the study is focused on assessing and valuating the genetic efficiency of pearl millet genotypes for the accumulation of iron and zinc content in grain. Enhancement of mineral nutrition in grain is essential to eradicate human mineral malnutrition, especially in resource-poor populations of developing nations. For the future, development of genotypes having higher nutrient use efficiency, especially for iron and zinc, is important to enable production on many soils. This research can significantly increase the mineral content of grain and enable other agronomic advantages in crop plants.


Ramesh Thangavel

Mr. Ramesh Thangavel began his Ph.D. program in 2008 in Soil Science and Agricultural Chemistry at the Indian Agricultural Research Institute (IARI) in New Delhi. His dissertation title is "Stocks and Quality of Soil Organic Matter under Different Land Use Systems in East Khasi Hills of Meghalaya." Objectives of his project include quantifying and qualifying soil organic matter stocks in different land use systems under slash and burn cultivation, and studying carbon stability mechanisms in Northeast India. For the future, this could lead to great reduction in soil erosion and much improved land use patterns.

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

Application deadline is June 30 each year. Further information and online application instructions and forms for the scholar award program can be found at the website: >www.ipni.net/scholar<. BC INDIA

Introduction to this Special Issue

IPNI

Welcome…

You are reading the third issue of *BETTER CROPS-INDIA*, first introduced in 2007 and published by the International Plant Nutrition Institute. Following a similar style as our popular quarterly publication, Better Crops with Plant Food, this special publication is the result of considerable effort for the India Programme staff and many 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

Zinc-Enriched Urea Improves Grain Yield and Quality of Aromatic Rice

By Gulab Singh Yadav, Dinesh Kumar, Y.S. Shivay, and Harmandeep Singh

Zinc-deficiency is widespread in the rice-growing tracts of northern India. The use of Zn-enriched prilled urea formulations assures better quality control than with Zn sulphate ($ZnSO_4$), which is being sold to farmers in India but has quality issues. In this study, we found $ZnSO_4$ to be a better source to enrich prilled urea than Zn oxide (ZnO). For aromatic rice production, 1.0% Zn-enriched urea ($ZnSO_4$) was most effective in realising higher grain yield and economic return.

In India, rice is the most important food crop, occupying 44 million (M) ha of land and producing 141 M t of grain annually. But the per hectare yield of rice (3.21 t/ha) for India, though increasing marginally, is still well below the world's average yield of 4.15 t/ha. Furthermore, the aromatic rice varieties occupy a prime position in national and international markets due to their excellent quality characters, viz., aroma, fineness, and kernel length for cooking.

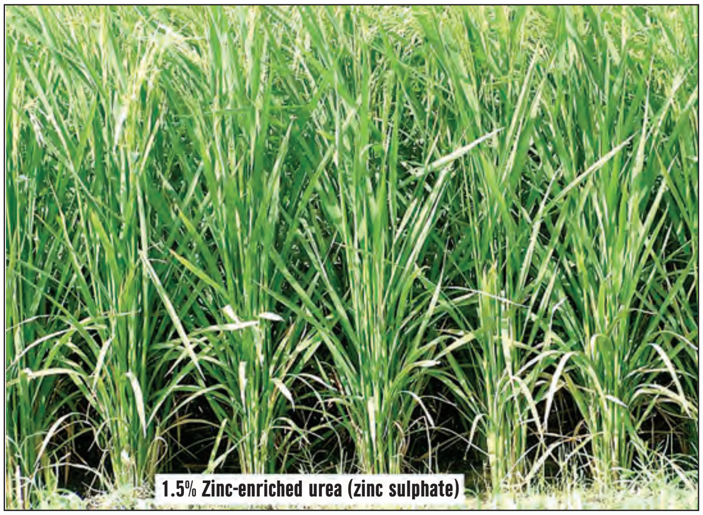
The use of macronutrients and micronutrients is important to increase aromatic rice yields and improve the quality of grains. Besides N, P, K, and S, Zn has gained maximum attention of late. The apparent reason for this is the overwhelming dominance of Zn deficiency in Indian soils and crops compared to other nutrients (Rattan et al., 1997). Increasing cropping intensity and accompanying changes in the soil and fertiliser management practices have lowered the Zn status of soils and its availability, especially in the Indo-Gangetic plains of India where rice-wheat cropping system is being practiced on a large-scale (Prasad, 2005).

View of research plots.

The recommendation for Zn, which is generally marketed as Zn sulphate heptahydrate ($ZnSO_4 \bullet 7H_2O$), varies from 10 to 25 kg/ha/season, depending upon the crop, environmental, and soil conditions. One of the major issues that farmers in India are facing is the availability of good quality $ZnSO_4$. Therefore, a good quality Zn-enriched urea (ZEU) manufactured by a fertiliser company would be ideal. Government of India's Fertiliser Control Order (FCO) has a provision for manufacturing and coating of 2.0% Zn onto urea. But very limited scientifically-valid data are available on the evaluation of Zn-coated urea in aromatic rice. We conducted a field experiment at the Indian Agricultural Research Institute (IARI), New Delhi, during *kharif* (summer monsoon) seasons (July-October) of 2005 and 2006 to evaluate the effectiveness of Zn-enriched urea formulations on grain yield and quality of aromatic rice in a sandy clay loam soil. The experimental soil had low levels of available Zn (0.68 mg/kg). The critical level of DTPA extractable Zn for rice grown on alluvial soils in the rice-wheat belt of North India varies from 0.38 to 0.90 mg/kg soil (Takkar et al., 1997). The soil contained 0.53% organic C, 0.05% total N, 14.5 kg/ha available P and 247 kg/ha available K at the start of the experiment. The initial soil pH was 8.2. New Delhi has a semi-arid and sub-tropical climate with hot and dry summers and cold winters. The mean annual rainfall is about 710 mm, most of which (about 84%) is received between July and September.

In our experimental layout, there were a total of 10 treatments. Basic treatments consisted of eight combinations of two Zn-enrichment materials ($ZnSO_4$ and ZnO) and four levels of Zn-enrichment (0.5, 1.0, 1.5, and 2.0% w/w of prilled urea). In addition, there were two other treatments including a no Zn control (only PU) and $ZnSO_4$ at 5 kg Zn/ha (soil application)

Abbreviations and notes for this article: PU = prilled urea (common urea); Zn = zinc; ZEU = zinc-enriched urea; ZnO = zinc oxide; $ZnSO_4$ = zinc sulphate; DAT = days after transplanting; HRR = Head rice recovery; N = nitrogen; P = phosphorus; K = potassium; S = sulphur; C = carbon; CD = Critical Difference, equivalent to Least significant Difference.



Plot showing rice with 1.5% Zn-enriched urea treatment ($ZnSO_4$).

Table 1. Grain yield, agronomic efficiency, and economic return of Zn use in aromatic rice as affected by Zn-enriched urea formulations.

Treatment	Zn rate, kg/ha	Grain yield across two years, t/ha	Agronomic efficiency of Zn, kg grain increase/kg Zn	Economic return,[1] Rs/Re invested in Zn
PU	0	3.98	–	–
0.5% ZEU (ZnO)	1.3	4.25	208	13.3
0.5% ZEU ($ZnSO_4$)	1.3	4.44	353	22.7
1.0% ZEU (ZnO)	2.6	4.46	185	11.9
1.0% ZEU ($ZnSO_4$)	2.6	4.66	261	16.8
1.5% ZEU (ZnO)	3.9	4.68	179	11.5
1.5% ZEU ($ZnSO_4$)	3.9	4.96	251	16.1
2.0% ZEU (ZnO)	5.2	4.95	186	11.9
2.0% ZEU ($ZnSO_4$)	5.2	5.14	223	14.3
PU + 25 kg $ZnSO_4$/ha soil application	5.3	5.18	226	14.5
CD (p=0.05)	–	0.47	–	–

[1] Taking GOI procurement price of fine paddy at Rs.6.10 per kg, and cost of Zn at Rs.95/kg. Minor changes in price of these commodities will not change the conclusion.

Table 2. Effect of Zn-enriched urea formulations on grain quality of aromatic rice in second year of experimentation

Treatment	Zn rate, kg/ha	Hulling, %	Milling, %	Head rice recovery, %	Protein content, %
PU	0	70.2	63.7	52.4	6.6
0.5% ZEU (ZnO)	1.3	73.7	64.8	53.8	6.7
0.5% ZEU ($ZnSO_4$)	1.3	74.6	65.2	54.3	6.8
1.0% ZEU (ZnO)	2.6	74.8	65.6	54.5	6.9
1.0% ZEU ($ZnSO_4$)	2.6	75.6	66.3	55.1	7.0
1.5% ZEU (ZnO)	3.9	75.9	66.5	55.3	7.1
1.5% ZEU ($ZnSO_4$)	3.9	76.2	67.2	56.1	7.2
2.0% ZEU (ZnO)	5.2	76.3	67.8	57.2	7.3
2.0% ZEU ($ZnSO_4$)	5.2	78.5	69.3	58.3	7.6
PU + 25 kg $ZnSO_4$/ha soil application	5.3	75.8	66.2	55.2	7.2
CD (p=0.05)	-	2.6	2.7	2.1	0.6

+ prilled urea. In the soil application treatment, $ZnSO_4$ was applied on the soil surface (broadcast and incorporated), which is the general recommendation for rice in India (Rattan et al., 1997). The treatments were replicated thrice in a randomised block design. All plots received 120 kg N/ha as ZEU or PU. At final puddling, 60 kg P_2O_5/ha as single superphosphate and 40 kg K_2O/ha as KCl were broadcast. Nitrogen at 120 kg N/ha as PU or ZEU was band-applied in two equal splits – half at 10 DAT and the other half at panicle initiation (40 DAT). The ZEU supplied 1.3, 2.6, 3.9, and 5.2 kg Zn/ha for the 0.5, 1.0, 1.5, and 2.0% coatings, respectively. To make up for the short fall of N in ZEUs, calculated amounts of additional N as PU were added in plots receiving ZEUs. Two to three 25 day-old seedlings of basmati (aromatic) rice variety 'Pusa Sugandh 5' were transplanted on hills at a row x plant spacing of 20 cm x 10 cm in the second week of July during 2005 and 2006.

The increase in grain yield in ZEU treatments over prilled urea ranged from 7.7% (0.5% ZEU-ZnO) to 35.9% (2.0% ZEU-ZS). A 0.5% Zn-enrichment of PU through $ZnSO_4$ or ZnO did not give a significant increase in grain yield over PU **(Table 1)**. However, a significant increase in grain yield over PU was obtained with 1.0, 1.5, and 2.0% Zn-enrichment either with $ZnSO_4$ or ZnO-enriched ureas and with soil application of $ZnSO_4$. Among the three higher levels of Zn enrichment (1.0, 1.5 and 2.0%), the highest grain yield was obtained at the 2.0% level. But the economic return was highest at the 1.0% level in the case of $ZnSO_4$, and at the 2.0% level in case of ZnO. Further, 1.0% ZEU ($ZnSO_4$) gave much higher economic return than 2.0% ZEU (ZnO).

In general, $ZnSO_4$-enriched urea was a better source than ZnO-enriched urea at the same level of Zn enrichment. This could be due to better solubility of $ZnSO_4$-enriched urea than of ZnO-enriched urea at the same level of Zn enrichment as observed by Nayyar et al. (1990). Slaton et al. (2005) also observed that Zn fertiliser source, averaged over application times, significantly affected grain yield of rice at all sites with Zn fertilisation increasing yields by 12 to 180% compared with the unfertilised control.

Grain quality parameters were studied in year 2 of the study **(Table 2)**. Application of ZEUs improved the grain quality of rice significantly. In general, $ZnSO_4$-enriched urea had a higher percentage of hulling, milling, and head rice recovery (HRR) than ZnO-enriched urea at a same level of Zn-enrichment. For example, protein content and other quality parameters improved significantly with 1.5% ZEU ($ZnSO_4$), 2.0 % ZEU ($ZnSO_4$ or ZnO), and soil application of $ZnSO_4$. The lower levels of Zn-enrichment (0.5% or 1.0%) did not improve grain quality over the PU.

Conclusion

In this study, $ZnSO_4$ was a better source than ZnO for Zn-enrichment of prilled urea. A 1.0% coating may be sufficient for rice, with higher economic return per rupee invested in Zn. For improved grain quality, 1.5% Zn-enriched urea ($ZnSO_4$) may be more appropriate than other Zn formulations.

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Effect of Balanced Fertilisation on Rice Yield in a Multi-Nutrient Stressed Red and Lateritic Soil

By Debkanta Mandal, G.N. Chattopadhyay, Subrata Mandal, and Kaushik Majumdar

A 3-year study to assess the efficiency of balanced fertilisation on monsoon rice yield in a typically low yielding red and lateritic soil of West Bengal, India, revealed that a soil test-based recommendation of N, K, and Zn along with 25% higher level of P produced the highest grain yield (6.08 t/ha). Average uptake of nutrients correlated well with the yield of rice. Uptake of nutrients was strongly influenced by application of other nutrients in the fertilisation schedule. The best treatment produced significantly higher net returns over traditional or generally recommended nutrient management practices.

Red and lateritic soils represent 70 million ha of the land area in India (Sehgal, 1998). These soils are usually less productive due to various soil related constraints, including coarse texture, low water holding capacity, acidity, poor availability of N, P, and K, low organic C status, and both excessive and inadequate levels of several secondary and trace elements (Raychaudhury et al., 1963). A large area under this soil group in West Bengal remains in fallow or is monocultivated with monsoon (kharif) rice. However, productivity of rice in these soils is low due to multi-nutrient deficiencies and other allied problems. Besides, traditional N-dependent, imbalanced fertilization in these soils further aggravates its productive capacity. This study assesses the possibilities of increasing the yield potential of kharif rice through soil test-based, balanced nutrient use.

The study was conducted during the monsoon season of 2002 to 2004 in a farmer's field in the village of Kendradangal, Birbhum, located in a typical red and lateritic soil belt of West Bengal, India. The soil was sandy clay in texture having a pH of 5.1, 1.3% organic matter, CEC of 14.6 $cmol_+$/kg, and base saturation and acid saturation of 92% and 8%, respectively. Available N, P, K, and Zn content was 38, 15, 197, and 3.5 kg/ha, respectively as per the soil test report by Agro Services International Inc. (ASI), USA. Based on this report, a fertiliser dose of 168 kg N, 112 kg P_2O_5, and 112 kg K_2O/ha was recommended to achieve a targeted rice yield of 6.5 t/ha. Taking this treatment as a base line, 14 treatment combinations were developed with different combinations of N, P_2O_5, K_2O, and Zn. Two more treatments viz. state fertilizer recommendation (SR) and local farmers' fertilization practice (FFP) were also included **(Table 1)**. The experiment was laid out in a randomized block design replicated thrice with the plot size of 5 m x 2.5 m. Rice (var. MTU-7029) was transplanted at a spacing of 20 cm x 10 cm with two seedlings per hill.

Assessment of the data showed that variation in fertiliser application had a significant effect on grain yield of rice during all 3 years **(Table 1)**. The highest average grain yield (6.08 t/ha) was produced from T_9 comprised of 168 kg N, 140 kg P_2O_5, 112 kg K_2O, and 7 kg Zn per hectare. Thus, application of 25% more P than was recommended by soil testing helped to achieve the highest rice yield, which is primarily attributed to the high P-fixing capacity of these soils which tends to reduce the efficiency of the added P fertiliser (Dev and Rattan, 1998). In spite of adding other recommended nutrients in required amounts, the lowest average grain yield (2.86 t/ha) was observed in T_4 where P was omitted – a 49% yield decline owed to P alone. Straw yield and harvest index were also significantly influenced by variations in different nutrient combinations.

A soil test-based recommendation of N, K, and Zn, along with 25% higher P level, produced the highest yield of monsoon rice.

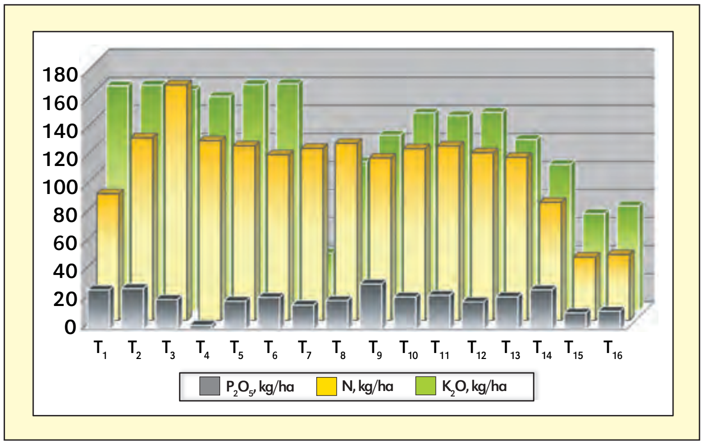

Figure 1. Effects of different treatments on availability of N, P_2O_5, and K_2O in soil after final harvest of kharif rice.

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; C = carbon; CEC = cation exchange capacity; SR = State recommendation; FFP = farmers' fertilisation practice; STB = soil test-based recommendation; CD = Critical Difference, equivalent to Least Significant Difference.

Mean availability of N in the soils after harvest of rice varied significantly under different treatments **(Figure 1)**.

Table 1. Effects of different treatments on grain yield, straw yield, and harvest index of kharif rice.

Treatment[1]	Grain yield, t/ha			Straw yield, t/ha			Harvest index, %		
	2002-03	2003-04	2004-05	2002-03	2003-04	2004-05	2002-03	2003-04	2004-05
$T_1 = N_{126}\text{-}P_{140}\text{-}K_{140}\text{-Zn}$	5.33 bcd	5.06 d*	5.01 d	7.18 d*	6.93 f	6.90 cde	42.61 c*	42.20 a	42.07 a
$T_2 = N_{168}\text{-}P_{140}\text{-}K_{140}\text{-Zn}$	5.33 bcd	5.77 b	5.77 b	7.11 de	7.90 c	7.88 bc	42.85 c	42.21 a	42.36 a
$T_3 = N_{210}\text{-}P_{140}\text{-}K_{140}\text{-Zn}$	5.44 bcd	4.62 f	4.70 e	7.3 c	9.32 a	9.27 a	42.70 c	33.14 b	33.64 b
$T_4 = N_{168}\text{-}P_{0}\text{-}K_{140}\text{-Zn}$	3.72 f	2.52 j	2.35 j	6.54 g	4.82 m	4.77 g	42.93 c	34.33 b	33.01 b
$T_5 = N_{168}\text{-}P_{84}\text{-}K_{140}\text{-Zn}$	5.67 ab	4.78 ef	4.76 e	7.62 b	6.55 g	6.51 ef	42.66 c	42.19 a	42.24 a
$T_6 = N_{168}\text{-}P_{112}\text{-}K_{140}\text{-Zn}$	5.65 ab	4.98 de	5.00 d	7.32 c	6.82 f	6.78 de	43.56 bc	42.20 a	42.44 a
$T_7 = N_{168}\text{-}P_{140}\text{-}K_{0}\text{-Zn}$	5.04 d	4.17 g	4.13 fg	6.94 f	5.71 j	5.62 fg	42.07 c	42.21 a	42.36 a
$T_8 = N_{168}\text{-}P_{140}\text{-}K_{84}\text{-Zn}$	5.45 abcd	4.60 f	4.65 e	7.18 d	6.30 h	6.27 f	43.15 bc	42.20 a	42.58 a
$T_9 = N_{168}\text{-}P_{140}\text{-}K_{112}\text{-Zn}$	5.87 a	6.19 a	6.17 a	7.80 a	8.48 b	8.44 ab	42.94 c	42.19 a	42.23 a
$T_{10} = N_{168}\text{-}P_{140}\text{-}K_{140}\text{-Zn}$	5.11 cd	5.69 b	5.76 b	7.06 e	7.79 d	7.75 bcd	41.98 c	42.21 a	42.64 a
$T_{11} = N_{168}\text{-}P_{140}\text{-}K_{140}$	5.07 d	4.31 g	4.24 f	7.18 d	5.90 i	5.86 fg	41.39 c	42.21 a	41.98 a
$T_{12} = N_{168}\text{-}P_{140}\text{-}K_{140}\text{-Zn}$	5.52 abc	5.42 c	5.39 c	7.28 c	7.43 e	7.39 bcde	43.13 bc	42.18 a	42.18 a
$T_{13} = N_{168}\text{-}P_{112}\text{-}K_{112}\text{-Zn}$ STB	5.59 ab	5.82 b	5.79 b	6.88 f	7.97 c	7.91 bc	44.83 bc	42.20 a	42.18 a
$T_{14} = N_{126}\text{-}P_{84}\text{-}K_{84}\text{-Zn}$	5.64 ab	4.18 g	4.11 g	7.14 de	5.73 j	5.69 fg	44.13 bc	42.18 a	41.94 a
$T_{15} = N_{80}\text{-}P_{30}\text{-}K_{30}$ FFP	3.59 f	2.76 i	2.54 i	5.06 i	5.15 l	5.09 fg	49.80 a	34.89 b	33.29 b
$T_{16} = N_{80}\text{-}P_{40}\text{-}K_{40}$ SR	4.32 e	3.02 h	2.98 h	6.04 h	5.51 k	5.44 fg	46.80 ab	35.40 b	35.39 b
CD (P = 0.05)	0.42	0.20	0.12	0.09	0.13	1.09	3.73	3.74	3.89

*Values followed by common letters do not differ significantly.

[1] Subscripted numbers following each nutrient refer to rates (kg/ha) of $N\text{-}P_2O_5\text{-}K_2O$.

Note: T_2, T_{10}, and T_{12} differs as plots received S, B, and S&B, respectively, in the previous-planted mustard crop.

In general, treatments with higher doses of N resulted in higher residual N in available form and vice versa. However, uptake of N was influenced by other nutrients which in turn influenced the residual available N levels of the soils. Comparing T_4 and T_5, differing only by the omission of P in T_4, showed that T_4 maintained a higher level of available N – owed to obviously lower N uptake due to poor crop yield in the absence of P. This trend was visible for the entire study, indicating that for improved utilisation of applied N, balanced use of other nutrients, especially P, is necessary.

Lower availability of P in several treatments significantly affected crop production. Residual availability of P was low in most treatments even after application of a comparatively higher dose of P fertiliser **(Figure 1)**. But a wide variation in availability of P was observed among treatments with the same level of P input. Treatments resulting in higher P uptake associated with increased yields (e.g., T_9) showed comparatively lesser amounts of residual P in available form in spite of using higher doses of P fertiliser. Treatments where P was added in high doses – but yield was low due to imbalanced use of other nutrients – also showed low residual availability of P. Thus, imbalanced use of nutrients not only failed to produce good yields, but also could not maintain the unutilised P in available form due to high P-fixation. Considering the critical role played by P in maintaining productivity of red and lateritic soils and also the rapid transformation of this nutrient to insoluble forms through P-fixation (Mandal and Chatterjee, 1972), some measures need to be taken to reduce the quantum of P-fixation in these soils. Use of organic matter and split applications of P fertiliser are known to improve P use efficiency of soils by reducing P-fixing capacity of soils (Dev and Rattan, 1998).

Mean availability of K was low in the soil under study

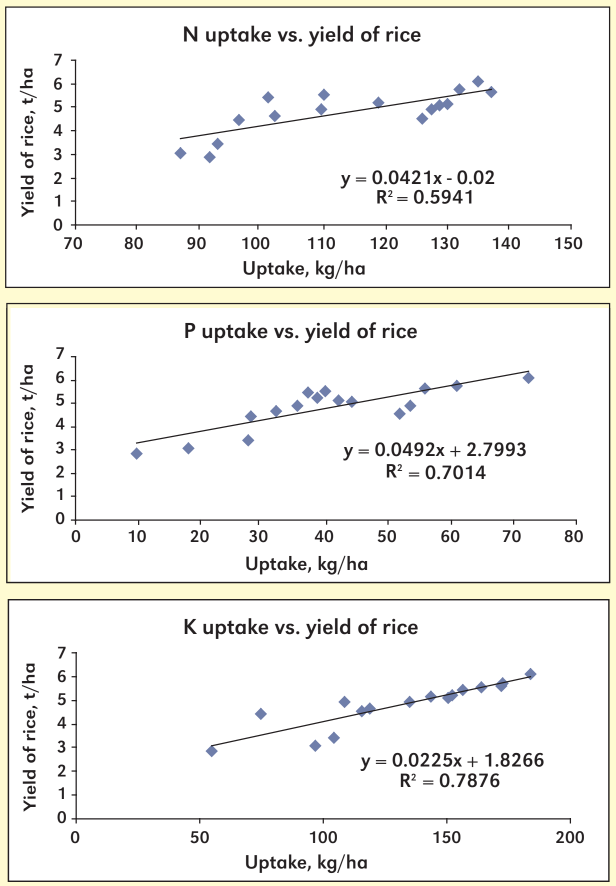

Figure 2. Grain yield and nutrient uptake relations in kharif rice.

Table 2. Economics of cultivation of kharif rice.

Treatment	Cost of cultivation, Rs.	Gross return, Rs.	Net return, Rs.
T_1	19,543	29,850	10,307
T_2	20,005	32,678	12,673
T_3	20,467	29,828	9,361
T_4	16,067	17,528	1,461
T_5	18,430	29,484	11,054
T_6	19,217	30,232	11,015
T_7	18,836	25,904	7,068
T_8	19,537	28,448	8,911
T_9	19,771	35,344	15,573
T_{10}	20,005	32,118	12,113
T_{11}	19,905	26,486	6,581
T_{12}	20,005	31,622	11,617
T_{13} STB	18,983	33,204	14,221
T_{14}	17,737	26,914	9,177
T_{15} FFP	14,925	17,860	2,935
T_{16} SR	15,289	20,596	5,307

Cost of fertiliser: urea at Rs.5; SSP at Rs.4.5; KCl at Rs.5; DAP at Rs.10.
Cost of seeds of paddy at Rs.10/kg.
Labour cost at Rs.60 per labourer per day.
Price of paddy grain at Rs.5/kg; paddy straw at Rs.600/tonne.

(Figure 1). Such restricted availability of K in red and lateritic soils has been reported by Ghosh and Hassan (1976). Use of K fertiliser tended to increase the residual available soil K status. There was a distinct declining trend in the availability of residual K in soil after rice cultivation where no K was included in the fertilization schedule. The submerged condition of rice soils probably aided further reduction of the available K status by causing considerable leaching of K due to poor water retention and low CEC of red and lateritic soils (Panda et al., 1991).

Average nutrient uptake by rice varied from 87 to 137 kg/ha for N, 10 to 72 kg/ha for P_2O_5, and 55 to 184 kg/ha for K_2O under the different treatments. The mean yield of rice for three seasons was significantly correlated with uptake of N, P, and K **(Figure 2)**. Such correlations highlight the importance of soil test-based fertiliser application in kharif rice as was earlier observed by Mukhopadhyay et al. (2008). That nutrient uptake is an interdependent function of other applied nutrients was further highlighted by T_7. Its high dose of P, without any K input, resulted in very low P uptake (data not shown). One important role of K in plant nutrition is to facilitate the uptake of other nutrients, including P. Under the prevailing low K status of red and lateritic soil, exclusion of K in the fertilisation schedule tended to restrict the uptake of P that in turn affected crop yield. On the other hand, T_7 showed comparatively higher uptake of K than T_4 – a P omission treatment. Here very low availability of P probably acted as the major limiting factor, thus affecting yield of rice and uptake of K. These results again emphasize the importance of balanced fertilisation in providing adequate nutrition to the plants. This study showed that removal of nutrients per tonne of rice grain yield varied between 18.6 to 32 kg for N, 3.4 to 11.9 kg for P_2O_5, and 16.8 to 31.6 kg for K_2O (data not shown). The highest average yield of 6.08 t/ha was obtained at a removal of 22.2 kg N, 11.9 kg P_2O_5, and 30.3 kg of K_2O per tonne of grain yield.

Economic calculations **(Table 2)** showed that net return was highest in the T_9 which provided the ASI recommended doses of N, K_2O, and Zn, and 25% more P_2O_5 than the ASI recommendation. Net return in the above treatment was Rs. 12,600/ha higher than the FFP and about Rs. 10,200/ha more than the current nutrient management strategy recommended by the State.

Conclusion

The study revealed that yield target-based balanced use of different nutrients constitutes the key for efficient nutrient management of monsoon rice under red and lateritic soils. Adoption of such balanced fertilisation not only resulted in larger yield levels, but also fetched higher economic benefits and showed excellent sustainability in yields. While applying nutrients in a balanced manner, due care should be exercised to use fertilisers at adequate amounts so that the doses of the nutrients can sustain expected yield levels. In addition, the behaviours and efficiency levels of different fertilisers in a particular soil should also be given due importance.

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IPNI Crop Nutrient Deficiency Photo Contest—2010

As the 2009 edition of the annual contest closes and the process of judging entries begins, the International Plant Nutrition Institute (IPNI) would first like to thank all past contestants and secondly would like to announce plans to continue sponsorship of a photo contest during 2010.

"This contest was initially designed to appeal to the competitive spirit of all who work in support of crop production," said IPNI President Dr. Terry Roberts. "It is apparent that each year's set of entries add to a great collection of documented examples of crop nutrient deficiency."

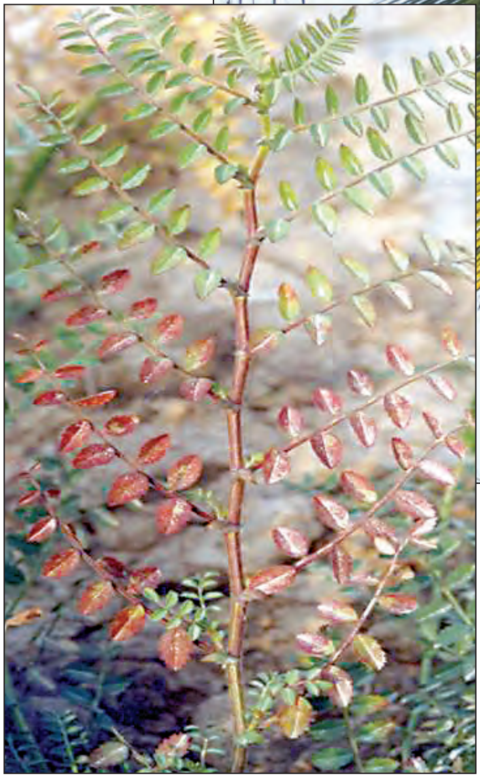
Some specific supporting information is required for all entries, including:

- 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 • and a Grand Prize of US$200 will be offered for the best overall photo entry.

Photos and supporting information can be submitted until December 15, 2010 and winners will be announced in January of 2011. 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 2008 edition of the contest.

Phosphorus deficiency in coconut (submitted by S. Srinivasan, Agricultural College, Tamil Nadu Agricultural University, Killikulam, Vallanad.)



Phosphorus deficiency in chickpea (submitted by Ch. Srinivasarao, Central Research Institute for Dry Land Agriculture, Hyderabad).

Entries are encouraged from all regions of the world. However, entries can only be submitted electronically as high resolution digital files to the 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

Site-Specific Nutrient Management in 'Mosambi' Sweet Orange

By A.K. Srivastava, Shyam Singh, V.S. Diware, and Harmandeep Singh

Site-specific nutrient management (SSNM) increased the yield and improved the quality of sweet orange when compared with fertiliser treatments based on existing recommendations or farm practice. This, along with the higher net economic return with SSNM, makes the case for large-scale adoption of SSNM to help reduce the gap between the actual and potential productivity of 'Mosambi' sweet orange orchards.

Citrus fruits are grown in an area of 7.12 lakh ha in India with a production of 59.77 lakh t and a productivity of 8.3 t/ha. Among the citrus fruits in India, sweet orange is the second most important fruit, occupying an area of 1.26 lakh ha with a production of 21.1 lakh t and a productivity of 16.7 t/ha. The commercially grown varieties of sweet oranges in India are: 'Jaffa', 'Valencia', 'Hamlin', and 'Malta' in Punjab, Himachal Pradesh, and Rajasthan; 'Sathgudi' orange in Andhra Pradesh; and 'Mosambi' in the Marathwada region of Maharashtra.

The productivity of sweet orange in India is significantly lower than in some of the frontline citrus growing countries like Brazil, USA, Spain, and Italy (30 to 35 t/ha). Similarly, the average productivity of 'Mosambi' sweet orange orchards (14.9 t/ha) is comparatively lower among the different sweet orange varieties. One of the main reasons for low sweet orange orchard productivity in the soils of Marathwada region is multiple nutrient deficiencies. The soils of this region are mostly derived from basaltic parent material and are commonly deficient in multiple nutrients, including N, P, Fe, Mn, and Zn (Srivastava and Singh, 2004). That is why the conventional nutrient management strategy based mainly on macronutrient application in citrus orchards has not been very successful in raising the productivity level (Srivastava et al., 2006). Soil test-based site-specific nutrient management (SSNM) offers a tangible option to address these nutritional constraints and to harness the productivity potential of specific orchard sites.

We conducted a field experiment for 3 years (2006-07 to 2008-09) at Narkhed Tehsil in Nagpur, Maharashtra, to evaluate whether soil test-based SSNM improves 'Mosambi' productivity, fruit quality, and economics of production. An 8-year-old 'Mosambi' sweet orange orchard was used with scion of sweet orange (*Citrus sinensis* Osbeck) budded on rough lemon rootstock (*Citrus jambhiri* Lush). The plant-to-plant and row-to-row distance was 6 m each, which results in a plant population of 278 trees/ha . The site had an alkaline, calcareous soil (Typic Haplustert) with available N, P, K, Fe, Mn, and Zn contents of 231, 25, 417, 25, 18 and 2.20 kg/ha, respectively. The climate of 'Mosambi' growing belts in the Marathwada region is characterised by hot and dry pre-monsoon summer months (March to May), followed by well expressed monsoon months (June to September). The mean summer (April, May, and June) to mean winter (December, January, and February) temperatures vary from 42° to 38 °C. The average annual rainfall of the region is 800 mm, of which 80 to 90% is received during monsoon months. For the experiment, we designed 17 different fertiliser treatments as outlined in **Table 1**. These fertiliser treatments were designed based on: a) the standard analysis of soil macronutrient, secondary nutrient, and micronutrient status of the experimental soil prior to the start of the experiment, and b) fertiliser recommendations designed to evaluate if up to 300% of the recommended doses can improve yield and/or fruit quality. In each of the experimental years, fertiliser application was split into three equal doses coinciding with the emergence of new flush in the months of April, August, and October. Different fruit quality parameters viz., TSS was determined using hand refractometer, juice content volumetrically, and acidity tritrimetrically as per commonly followed procedures.

Abbreviations and notes: FFP = farmers' fertiliser practice; RDF = recommended doses of fertilisers; SSNM = site-specific nutrient management; TSS = Total soluble solids; N = nitrogen; P = phosphorus; K = potassium; Fe = iron; Mn = manganese; Zn = zinc; lakh = 100,000; Ca = calcium; CD = Critical Difference, equivalent to Least Significant Difference.


Immature sweet oranges in Nagpur, Maharashtra.

Yield Response

Fruit yield is a good index of orchard productivity. A significantly higher 'Mosambi' yield was obtained with SSNM as compared to RDF and FFP **(Table 1)**. This indicates the potential of SSNM to reduce the gap between actual and potential productivity of 'Mosambi' sweet orange orchards.

The RDF, FFP, and SSNM treatments all had similar N:P:K ratios, and the only change was in the levels of N, P, and K applied with SSNM using double the amounts of macronutrients **(Table 1)**. This indicates that in crops where the traditional macronutrient ratio approach to guiding fertiliser application is well established, SSNM does not try to change the approach. Instead, it tries to include the effect of other related factors (like

Table 1. Response of different treatments on growth and yield of 'Mosambi' sweet orange (pooled data of 3 years).

Treatments[1]	Fruit yield, kg/tree	-------- Quality --------		
		Juice, %	TSS, %	Acidity, %
$T_1 = N_0-P_{200}-K_{300}-M_1$	37.9	47.2	8.5	0.46
$T_2 = N_{400}-P_0-K_0-M_1$	37.7	45.1	8.3	0.41
$T_3 = N_0-P_0-K_{300}-M_1$	36.2	45.8	8.3	0.46
$T_4 = N_{400}-P_{200}-K_0-M_1$	42.0	46.5	8.3	0.40
$T_5 = N_{400}-P_{200}-K_{300}-M_1$ (RDF)	44.4	48.3	8.9	0.44
$T_6 = N_{400}-P_{200}-K_{300}-M_2$	46.4	47.7	8.6	0.46
$T_7 = N_{400}-P_{200}-K_{300}-M_0$ (FFP)	40.2	46.9	8.3	0.48
$T_8 = N_{800}-P_{400}-K_{600}-M_1$ (SSNM)	61.4	50.9	9.5	0.44
$T_9 = N_{800}-P_{400}-K_{900}-M_1$	58.8	49.6	9.3	0.51
$T_{10} = N_{800}-P_{400}-K_{1200}-M_1$	57.9	49.9	9.3	0.61
$T_{11} = N_{800}-P_{400}-K_{1200}-M_2$	56.7	49.8	9.2	0.57
$T_{12} = N_{1200}-P_{400}-K_{300}-M_1$	53.6	47.9	8.7	0.47
$T_{13} = N_{1200}-P_{400}-K_{600}-M_1$	54.2	48.9	8.8	0.49
$T_{14} = N_{1200}-P_{400}-K_{900}-M_1$	51.2	49.7	8.9	0.58
$T_{15} = N_{1200}-P_{400}-K_{1200}-M_1$	50.8	50.5	8.8	0.63
$T_{16} = N_{1200}-P_{400}-K_{300}-M_0$	48.3	46.7	8.4	0.53
$T_{17} = N_{1200}-P_{400}-K_{300}-M_1S_1$	48.7	48.3	8.8	0.47
CD ($p = 0.05$)	1.98	1.2	0.27	0.031

[1] Subscripts after N, P, and K indicate rates applied, kg/ha

M_0 = no micronutrients

M_1 = micronutrients consisting of 250 g each of $FeSO_4$, $MnSO_4$, and $ZnSO_4$/tree

M_2 = micronutrients consisting of 500 g each of $FeSO_4$, $MnSO_4$, and $ZnSO_4$/tree

S_1 = $CaSO_4$ and $MgSO_4$ each at 250 g/tree

levels, etc.) to better nutrient management decisions. Also, as the established macronutrient ratio was altered (T_8 vs T_9 and T_{10}), we observed a significant decline in 'Mosambi' yield.

Micronutrient application had a significantly positive effect on 'Mosambi' yield (FFP vs RDF treatments) under the experimental conditions **(Table 1)**. Their effect was more pronounced at lower levels of N, P, and K (T_5 vs T_6 vs T_7) than at higher levels (T_{10} vs T_{11}). However, the application of secondary nutrients, i.e., Ca and Mg, caused yield declines (T_{12} vs T_{17}). This was probably due to the increased competition for plant uptake between these nutrients and K.

We observed a variety of nutrient deficiencies in nutrient omission plots as a cumulative effect of 3 years of experimentation. For example, N deficiency was observed where no N was applied for three successive years (T_1), K deficiency was observed in the form of small fruit size where no K was applied (T_2), and Fe, Mn, and Zn deficiencies were observed where no micronutrient application was done in the 3 years of experimentation (T_7). These deficiencies were confirmed using leaf analysis, and indicated that there is a continuous mining of nutrients in 'Mosambi' sweet orange orchards. And unless we supplement the nutrients using a SSNM strategy, attaining potential productivity of these orchards is almost impossible.

Table 2. Analysis of economic returns from SSNM versus RDF and FFP.

Treatment	Cost[1], 000' Rs/ha	Benefit[2], 000' Rs/ha	Net returns, 000' Rs/ha
T_7 (FFP)	16.5	110.8	94.3
T_5 (RDF)	21.7	121.9	100.2
T_8 (SSNM)	32.5	169.0	136.5

[1] Includes operational charges consisting of two weedings, basin cleaning, and labour charges for fertiliser application (Rs.10,000/ha) plus the cost of fertilisers including urea (Rs.8/kg), SSP (Rs.7/kg), KCl (Rs.8/kg), gypsum (Rs.2/kg), $FeSO_4$ (Rs.15/kg), $MnSO_4$ (Rs.30/kg), and $ZnSO_4$ (Rs.30/kg).

[2] As per existing farm rate (Rs.10,000/t).

Fruit Quality Response

Juice content, TSS, and juice acidity are the three most important parameters used to determine orange quality. And just like the yield response, SSNM had a significant positive impact on these parameters as compared to RDF and FFP treatments **(Table 1)**.

Omission of K (T_4) from the RDF (T_5) significantly reduced juice percentage and TSS, suggesting a strong influence of K on quality parameters of sweet orange **(Table 1)**. However, even when we applied more K but disturbed the balanced ratio of macronutrients (T_8 vs T_9 and T_{10}), the juice content again declined significantly. Additionally, higher K rates increased juice acidity, regardless of the level of NP input.

Inclusion of micronutrients produced a significantly favorable response on juice and TSS (T_7 vs T_5 and T_{16} vs T_{12}). Inclusion of secondary nutrients increased juice yields significantly, but did not have a significant effect on TSS **(Table 1)**.

Economics of Nutrient Management Approaches

Just like its favorable response on 'Mosambi' yield and quality, SSNM provided a comparatively higher net return than either RDF or FFP **(Table 2)**. The cost of cultivation increased marginally with SSNM compared with RDF and FFP, but this increase was offset by a remarkable increase in net benefit, realised mainly through increased 'Mosambi' yields.

The results of this study clearly show the need to a) maintain a balance between macronutrients and micronutrients in deciding need-based, optimum fertiliser doses and b) revise the current fertiliser recommendation system to realise full productivity potential on a given soil type.

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Evaluation of Nutrient Management Options for Yield, Economics, and Nutrient Use Efficiency

By M.S. Gill, A.K. Shukla, M.P. Singh, O.K. Tomar, Raj Kumar, K. Majumdar, and K.N. Tiwari

Sustainable high yield agriculture is India's top-most agenda for food security and environmental safety. But there is need to refine most farming situations, if not all, to sustain productivity and prevent the ever-increasing problems related to soil fertility deterioration. This paper evaluates the nutrient management options for cereals, pulse, oilseed, and fodder-based cropping systems in order to diversify crop production, maximise economic gain, and sustain optimal nutrient use efficiency and soil fertility.

Site-specific nutrient management (SSNM) considers indigenous nutrient supply of the soil and productivity targets capable of sustained high yields on one hand, and assured restoration of soil fertility on the other. With this approach, the present food grain production could be achieved from half of the presently irrigated area (Tiwari et al., 2006; Gill et al., 2008). Meanwhile, the remaining half could be better utilised in crop diversification efforts involving legumes, pulses, vegetable, and other high value crops.

After breaking current yield barriers by attaining 12 to 16 t/ha within rice-rice and rice-wheat cropping systems at 17 locations in India under IPNI-supported research projects on SSNM with Project Directorate for Cropping System Research (PDCSR)(Tiwari et al., 2006), it was planned to devise SSNM schedules for pulse, oilseed, and fodder-based cropping systems. An on-station experiment was conducted during 2007-08 in Meerut to evaluate the performance of five nutrient management options including: (1) Farmers' fertiliser practice (FFP), (2) State fertiliser recommendation (SR), (3) Improved state recommendation (ISR; uses a 25% higher dose of N and 50% higher doses of P and K than the SR), (4) state soil testing laboratory recommendation (SSTR), and (5) SSNM within five important cropping systems (i.e., sesamum-wheat, groundnut-wheat, pigeon pea-wheat, maize-wheat, sorghum (fodder)-wheat vis-à-vis a rice-wheat cropping system).

The climate of Meerut is semi-arid sub-tropical, with hot, dry summers and cold winters. The average annual rainfall is 810 mm, 75% of which is received between July and September. The soil of the experimental site was sandy loam in texture (160 g clay/kg, 190 g silt/kg, and 630 g sand/kg), alkaline in reaction (pH 8.2), low in organic C (0.48%), high in P (29 ppm), low in available K (166 kg/ha), and low in S (5.6 ppm). The available micronutrient (i.e., Zn, Mn, Cu, Fe, and B contents were 0.55, 12.3, 2.39, 47.3, and 0.41 ppm, respectively.

The experiment was conducted in split plot design with three replications. The treatment detail for the kharif crops is depicted in **Table 1**. Wheat was grown in the same layout, using NPK fertilisers only, to assess the carryover effect of the secondary and micronutrient applications. Fertiliser sources included urea, diammonium phosphate, potassium chloride, gypsum, zinc sulphate, and sodium tetra-borate.

Economics of the various fertiliser scheduling were calculated on the basis of cost of cultivation **(Table 4)** plus fertiliser cost. For net return, the total cost of cultivation was deducted from the gross return of the system. Gross return calculations used both procurement prices and local prices where applicable (e.g., sorghum fodder value based on local price).

Abbreviations and notes: ISR = improved state recommendation; SR = state recommendation; FFP = farmers' fertilisation practices; N = nitrogen; P = phosphorus; K = potassium; S = sulphur; Zn = zinc; Mn = manganese; Cu = copper; Fe = iron; B = boron; C = carbon; CD = Critical Difference, equivalent to Least Significant Difference.

Yield and System Productivity

The yields of kharif crops varied with nutrient management options, but maximum economic yields were registered under SSNM in all crops **(Table 2)**. The ISR gave the second highest economic yield. Higher yields in these two treatments is ascribed to better yield attributes due to adequate and balanced supply of nutrients as per crop demand through better consideration of the indigenous nutrient supply capacity of soil (Shukla et al, 2004). Response to nutrient management options varied with fertiliser treatment. The SR and STLR produced comparable results for most crops, but were inferior to either ISR or SSNM, highlighting the effects of inadequate nutrients supply. Improved nutrient management also enhanced the yields of sorghum fodder through enhanced leafstalk ratio and diameter of stem.

Grain yield of wheat rose after these kharif crops on same layout without application of secondary and micronutrients. Wheat yields after rice, maize, pigeon pea, groundnut, sesamum, and sorghum fodder followed much the same trend as was observed in the preceding crops. Wheat yields were highest under SSNM and lowest under FFP. The highest wheat yield under SSNM (6.57 t/ha) was registered after maize harvest, while the lowest production (5.81 t/ha) was recorded after sorghum fodder harvest. Enhanced wheat yields under SSNM and ISR is attributed to longer ear size, greater number of grains/ear, and higher numbers of effective tillers (data not shown). Although the magnitude of the response varied with cropping system, the application of secondary and micronutrients in most kharif crops caused significant residual effects on succeeding wheat crops

System productivity across treatments, in terms of wheat equivalent yield [WEY-{(kg yield of other crop in wheat based system x unit price of that crop)/unit price of wheat) + actual wheat yield}], was highest in the rice-wheat (9,709 kg/ha) followed by maize-wheat (9,122 kg/ha), groundnut-wheat (7,976 kg/ha), pigeon pea-wheat (7,619 kg/ha), sesamum-wheat (7,069 kg/ha), and was lowest in sorghum fodder-wheat (6,504 kg/ha). Across cropping systems, system productivity (WEY) was 10.1, 20.4, 11.1, and 26.3% higher in the SR, ISR, STLR, and SSNM compared to the FFP. On average, SSNM had a 6% edge over the ISR. This improvement is attributed to secondary and

Table 1. Treatment details of different crops/cropping system.

Treatments	Grain/dry fodder yield, kg/ha					
	N	P_2O_5	K_2O	S	$ZnSO_4$	Borax
Sesamum						
FFP	25					
SR	35	30	30			
ISR	43.75	37.5	30			
STLR	43.75	22.5	30			
SSNM	60	45	45	40	25	
Pigeon pea						
FFP	22.5	58				
SR	15	4520				
ISR	18.75	56.25	30			
STLR	18.75	33.75	25			
SSNM	30	60	90	40	25	
Groundnut						
FFP	22.5	58				
SR	20	30	45	25		
ISR	25	37.5	68	31.25		
STLR	25	22.5	56	31.25		
SSNM	40	60	90	45	25	5.0
Rice						
FFP	180	60		25		
SR	180	75	60		25	
ISR	187.5	93.75	90		31.5	
STLR	187.5	56.25	75		31.5	
SSNM	180	60	90	45	40	5.0
Maize						
FFP	120	58				
SR	120	60	90			
ISR	150	75	90			
STLR	150	45	75			
SSNM	150	75	90	40	40	
Sorghum						
FFP	35	11.5				
SR	120	60				
ISR	150	75				
STLR	150	45				
SSNM	120	60	60	30	25	

Note: Wheat is grown after each crop with the same treatment structure following the recommendation of wheat crop.

micronutrient application within the SSNM treatment, which is supported by the IPNI-PDCSR collaborative programme on SSNM (Tiwari et al., 2006) and long-term experiments conducted at PDCSR (Shukla et al., 2009).

The largest gap between the SSNM and FFP was recorded in sorghum fodder-wheat (38%), followed by sesamum-wheat (33%), rice-wheat (30%), and groundnut-wheat (28%). The smallest gaps were recorded in maize-wheat (24%), and in pigeon pea-wheat (24%). The increase over SR, ISR, and STLR varied from 14 to 20%, 5 to 8%, and 12 to 18%, respectively **(Figure 1)**.

Nutrient Uptake

The total NPK uptake varied across nutrient management options depending on system productivity and the nutrient content in the grain and straw of the different crops **(Table 3)**. On average, the greatest NPK uptake was recorded in the maize-wheat system (681 kg/ha) followed by rice-wheat (651 kg/ha), pigeon pea-wheat (516 kg/ha), sorghum fodder-wheat (461 kg/ha), sesamum-wheat (426 kg/ha), and lastly groundnut-wheat (408 kg/ha). However, the nutrient content in groundnut seed (and foliage) was very high despite relatively lower seed yields. Stalk yield of sesamum was much higher than that of groundnut, which contributed to greater total N and K uptake in sesamum.

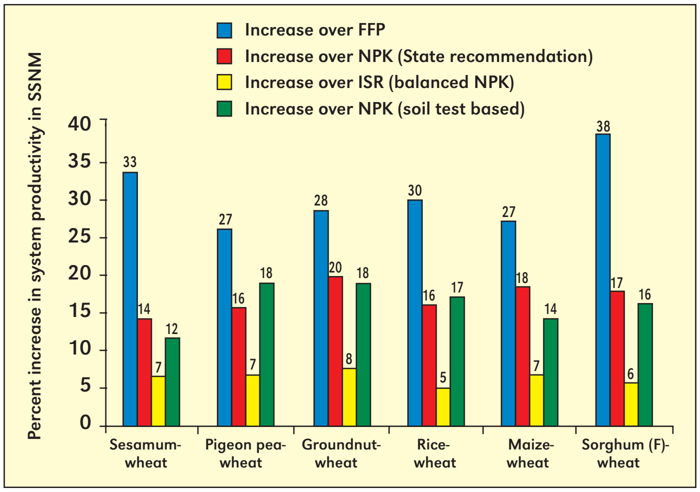

Figure 1. Percent increase in system productivity in SSNM treatment over other nutrient management options under different cropping systems.

Maximum NPK accumulation was registered in SSNM, followed by ISR, and was lowest in FFP. The STLR and SR options were statistically comparable, but both were superior to FFP. The effect of secondary and micronutrient application was clearly visible on NPK uptake – observed by comparing the ISR (with adequate NPK only) against SSNM (adequate NPK plus S, Zn, and B). This increase could be accredited to better crop metabolism of NPK. Since FFP lacked K fertiliser, the practice not only adversely affected K uptake, but also uptake of N and P, because of low yields and reduced NP metabolism.

Accordingly, NPK use efficiency was much higher in SSNM compared to FFP. Addition of micronutrients in the SSNM schedule also increased internal nutrient use efficiency over the ISR. However, the magnitude of this increase varied among cropping systems **(Figure 2)**.

Effect on Soil Fertility

Soil nutrient status after one crop cycle was measured for available N, P, K, and S (data not shown). Trends found little effect on soil pH or electrical conductivity, but other parameters varied with nutrient management option and cropping system. Available N status was lowest in sorghum fodder-wheat, which was on a par with the maize-wheat system. Since N is the most mobile element in soil, its available status is highly unstable. However, available N status was invariably greater in the upper soil layer (0 to 15 cm) in all cropping systems. In sorghum, the available N status in lower layer (15 to 30 cm) was lowest among all the cropping systems. The ISR treatment showed higher available P contents in surface soils compared to other treatments. However, lower P contents in surface soils under SSNM over ISR revealed that P utilisation was better in SSNM due to secondary and micronutrient application. The P content in deep-rooted legume and fodder-based cropping systems was usually less than in cereal crops, owing to higher utilisation of P by legume and fodder crops. The treatment receiving fertiliser as per STLR had identical P contents as the SR in most cropping systems. The lowest soil K content was recorded in the

Table 2. Crop yields and system productivity as influenced by nutrient management options in different cropping systems.

Nutrient management options	System productivity (kg/ha) as wheat equivalent yield (WEY)																	
	Rice	Wheat	RWS*	Sesamum	Wheat	SWS*	Pigeon pea	Wheat	PWS	Groundnut	Wheat	GWS	Maize	Wheat	MWS	Sorghum (F)	Wheat	S(F)WS
FFP	6,971	4,571	8,422	713	4,252	5,950	1,526	4,867	6,916	1,351	5,143	7,099	5,766	5,114	8,079	41,619	4,390	5,381
SR	7,467	5,333	9,458	804	5,030	6,945	1,582	5,410	7,534	1,362	5,571	7,543	6,045	5,581	8,690	51,429	5,095	6,320
ISR	8,343	5,771	10,380	850	5,392	7,416	1,878	5,690	8,212	1,624	6,076	8,427	6,913	6,038	9,593	57,905	5,629	7,007
STLR	7,619	5,143	9,351	776	5,248	7,096	1,588	5,257	7,390	1,456	5,619	7,727	6,383	5,714	8,997	49,905	5,200	6,388
SSNM	9,257	5,819	10,933	998	5,564	7,940	2,144	5,876	8,756	1,934	6,286	9,085	7,732	6,276	10,253	67,810	5,810	7,424
Mean	7,931	5,328	9,709	828	5,097	7,069	1,744	5,420	7,619	1,545	5,739	7,976	6,568	5,745	9,122	53,733	5,225	6,504
CD ($p < 0.05$)	528	265	536	85	244	463	106	211	481	89	232	412	529	198	543	1,095	231	321

RWS = Rice-wheat system; SWS = sesamum-wheat system; PWS = pigeon pea-wheat system; GWS = groundnut-wheat system; MWS = maize-wheat system; and S(F)WS= sorghum (fodder)-wheat system.

Table 3. Total NPK uptake as influenced by nutrient management options under different cropping systems.

Nutrient manage-ment options	Total NPK uptake[1], kg/ha																	
	Rice-wheat			Sesamum-wheat			Pigeon pea-wheat			Groundnut-wheat			Maize-wheat			Sorghum (F)-wheat		
	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K
FFP	203	64	267	129	30	199	155	43	224	138	41	168	212	64	286	82	30	180
SR	239	80	298	152	38	224	182	53	256	149	46	183	234	77	329	178	40	239
ISR	276	92	341	165	43	237	218	64	297	180	58	211	254	96	374	211	51	271
STLR	244	76	305	159	37	231	178	49	247	158	49	184	251	80	348	175	39	237
SSNM	301	101	363	182	48	256	233	67	314	188	61	225	292	100	400	222	53	300
Mean	253	83	315	157	39	230	193	55	268	163	51	194	249	84	348	174	42	245
CD ($p < 0.05$)	22.8	7.5	19.6	13.2	4.1	18.5	15.3	5.2	18.9	12.8	4.2	20.7	13.4	6.8	24.0	17.8	3.4	14.3

[1] Plant uptake values are presented as elemental forms.

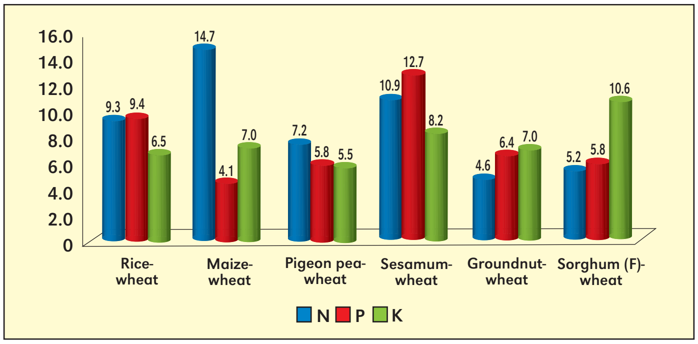

Figure 2. Percent increase in internal nutrient use efficiency in SSNM treatment over other nutrient management options.

pigeon pea-based system and sorghum fodder-based system. The higher soil K status in cereal-based systems is possibly due to higher application and reduced K uptake compared to the pulse-based systems. The available S content of surface soil in the maize-wheat, sorghum-wheat, and sesamum-wheat cropping systems was either below or near the critical limit. Application of gypsum in groundnut has resulted in enhanced available S status in all the treatments. SSNM had the highest soil S content after one crop cycle, although the magnitude of this increase was not very high as the succeeding crop of wheat was grown without secondary and micronutrient application. The available S content at the lower depth was usually less than the surface soil in all cropping systems except the pigeon pea-wheat system. Interestingly, a slight S build up was noted under SSNM, while K status sharply declined in the STLR, SR, ISR, and FP treatments.

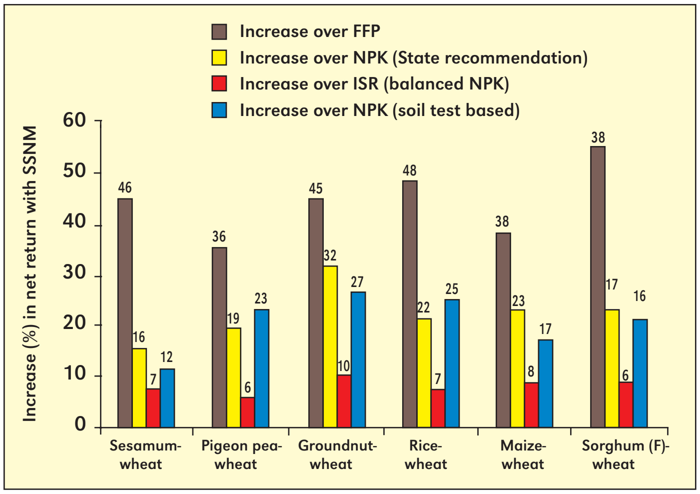

Figure 3. Percent increase in net return with SSNM treatment over other nutrient management options.

Economic Return

Economics is the dominant factor influencing the adoption of cropping systems. Across all options, the highest return (Rs.56,327) was recorded for the rice-wheat system, while

Table 4. Effect of nutrient management options on total net return of different cropping systems.

Nutrient management options	Sesamum-wheat	Pigeon pea-wheat	Ground nut-wheat	Rice-wheat	Maize-wheat	Sorghum fodder-wheat
	Total cost of cultivation, Rs./ha					
FFP	30,020	33,967	35,982	43,432	41,488	26,589
SR	30,830	34,408	38,078	45,115	41,956	29,267
ISR	31,758	35,421	39,301	46,570	43,456	30,542
STLR	30,940	34,442	38,399	45,269	42,279	29,477
SSNM	33,950	37,836	41,258	47,692	45,541	31,950
Mean	31,499	35,215	38,604	45,616	42,944	29,565
	Total net return, Rs./ha					
FFP	32,452	38,655	38,560	45,002	43,347	29,916
SR	42,091	44,697	41,123	54,192	49,284	37,090
ISR	46,112	50,809	49,181	62,418	57,274	43,034
STLR	43,565	43,149	42,735	52,922	52,191	37,599
SSNM	49,426	54,102	54,139	67,099	62,112	46,003
Mean	42,729	46,282	45,147	56,327	52,842	38,728
CD ($p<0.05$)	2,665	2,815	2,690	3,212	3,254	2,358

Note: Prices for N, P_2O_5, K_2O, S, Zn, and B were Rs.10.5, 16.5, 7.5, 26.5, 20, and 34 per kg. Prices for rice, sesamum, pigeon pea, groundnut, maize, and sorghum (fodder) were Rs.5.80, 15.60, 14.10, 15.20, 5.40, and 0.25 per kg. Labour cost = Rs105 per labourer per day. In addition, land lease cost (rental value), irrigation cost, and pesticides costs are included in the total cost.

the lowest (Rs.38,728) was registered in the sorghum fodder-wheat system (**Table 4**). The cost of cultivation was lowest in sesamum-wheat and this was comparable with the sorghum fodder-wheat system. Under SSNM, 8.1 to 17%, 6.3 to 11.3%, 2.6 to 7.7%, and 5.9 to 11.5% additional investment was accrued compared to FFP, SR, ISR, and STLR treatments, respectively. Similarly, the total net returns for the different systems were also greater by 36 to 55%, 16 to 32%, 6.0 to 10%, and 12 to 27%, respectively, over FFP, SR, ISR, and STLR (**Figure 3**). As for adoption of nutrient management options, the highest return was from SSNM, which furnished Rs. 67,099, 62,112, 54,139, 54,102, 49,426, and 46,003 in rice-wheat, maize-wheat, groundnut-wheat, pigeon pea-wheat, sesamum-wheat, and sorghum fodder-wheat, respectively.

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International Certified Crop Adviser Program Coming to India

The International Certified Crop Adviser (ICCA) program of the American Society of Agronomy (ASA) is coming to India in 2010. The ICCA program is a voluntary initiative that certifies candidates who successfully complete an exam which tests their knowledge on principles and practices associated with crop management, integrated pest management, nutrient management, and soil and water management.

Who are CCAs?

- CCAs are working mainly with the crop production and soil management industry, or government service. They are involved in providing recommendations to farmers on a daily basis, using scientific knowledge and experience to help solve real problems.

When will the certification exams be held?

- The first opportunity to be tested under the ICCA program in India will be in November of 2010. The exam will be offered in the states of Punjab and Haryana. Future expansion of the exam testing process is expected in 2011.

Who manages the exam in India?

- The exam is managed by a select committee of Indian experts working in the four core competency areas being tested. Candidates who are successful in passing the exam will present their education and work experience credentials to the ICCA certifying board, who are then in a position to approve the candidate for certification.

Watch for more details on the ICCA program in India in 2010. It is your opportunity to become part of the largest crop production certification program in the world.

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Response of Rabi Crops to Potassium

By Jag Pal Singh and Vinay Singh

Results from this comparative study revealed significant responses to K application in mustard, oat, and wheat. Crop yields responded significantly up to 90 kg K_2O/ha.

Intensive cropping with high yielding varieties over the last 50 years has resulted in a marked depletion of inherent K reserves in Indian soils. Potassium requirements of crops are often equal to N requirements and are three to five times higher than P. However, the current consumption per unit of gross cropped area of N (75 kg/ha) and P_2O_5 (29 kg/ha) are five and two times that of K (14 kg K_2O/ha), respectively (FAI, 2008). The scenario has been similar over the last 30 years as average K use has been about one-seventh of N and about one-third of P. Consequently, besides N and P, the deficiency of K is frequently reported from different parts of the country. Crop species, however, markedly vary in their response to K. Tiwari and Nigam (1985) reported mustard to be more responsive to K than wheat. The present investigation was undertaken to study the comparative response of different rabi crops to K application.

A field experiment was conducted at R.B.S. College Research Farm Bichpuri, Agra, during the rabi season of 2005 to 2007. The test soil had a pH of 8.0, EC (1:2.5) was 0.19 dS/m (non saline), and organic C content was 3.4 g/kg. The available N, P, and K contents were low (80, 5.8, and 112 mg/kg, respectively). Three rabi crops i.e. wheat (var. H.D. 2329), oat (var. Kent), and mustard (var. Rohini), were grown with treatments consisting of five K levels (0, 30, 60, 90, and 120 kg K_2O/ha) applied in the form of potassium chloride (KCl). All the treatments received recommended doses of N, P, S, and Zn at the time of sowing (wheat: 150, 60, 20, and 20 kg/ha; oat: 80, 60, 20, and 20 kg/ha; and mustard: 100, 40, 40, and 20 kg/ha). Sources included urea, diammonium phosphate, zinc sulphate, and elemental S. Grain and stover yields were recorded and K concentration was determined by flame photometer after plant samples were digested in a di-acid mixture (HNO_3: $HClO_4$: 4:1).

Results revealed an increase in grain and stover yields of mustard and both the cereals crops **(Table 1)**. The highest seed (2.24 t/ha) and stover yield (5.23 t/ha) of mustard was recorded with the application of 120 kg K_2O/ha. Differences in mustard yields obtained with 90 and 120 kg K_2O/ha were not significant. Potassium application at 90 kg K_2O/ha produced the highest grain (4.49 t of wheat and 2.34 t of oat) and straw (6.54 t of wheat and 3.44 t of oat) yields. Similar findings were reported by Meel et al. (1994) in oat, Singh and Singh (2002) in wheat, and Mishra (2003) in mustard. Returns over fertilizer cost steadily improved with K application rate through high single-year returns from investment in K across all rates studied **(Table 1a)**.

Among the crops, the highest K concentration was observed in mustard seed and stover and the lowest occurred in oat **(Table 2)**. Potassium application up to 120 kg K_2O/ha significantly increased K contents of all crops except oat grain, which did not respond beyond 90 kg K_2O/ha.

Abbreviations: N = nitrogen; P = phosphorus; K = potassium; S = sulphur; Zn = zinc; C = carbon; CD = Critical Difference, equivalent to Least Significant Difference.

Table 1. Effect of K on yield (t/ha) of selected rabi crops.

		K_2O applied, kg/ha					CD
Crop	Portion	0	30	60	90	120	(p = 0.05)
Wheat	Grain	3.62	3.76	4.10	4.49	4.52	0.30
	Straw	5.44	5.59	6.06	6.54	6.57	0.48
Oat	Grain	1.83	1.99	2.19	2.34	2.42	0.20
	Straw	2.76	2.98	3.25	3.44	3.55	0.27
Mustard	Seed	1.49	1.64	1.87	2.17	2.24	0.18
	Stover	3.66	4.03	4.47	5.04	5.23	0.59

Table 1a. Effect of K application on economic return over fertiliser cost (Rs./ha) and return on K investment (in parentheses) in selected rabi crops.

		K_2O applied, kg/ha				
Crop	Portion	0	30	60	90	120
Wheat	Grain	34,201 (-)	33,978 (6.5)	35,211 (11.2)	38,524 (13.5)	42,669 (10.5)
Oat	Grain	14,182 (-)	15,422 (5.6)	16,972 (6.3)	18,135 (5.9)	18,755 (5.1)
Mustard	Seed	24,916 (-)	27,483 (12.5)	31,538 (15.9)	36,895 (18.9)	37,974 (15.9)

Price per tonne of wheat grain = Rs.10,400; oat = Rs. 7,750; mustard = Rs. 18,600.
Cost per kg of fertilizer N, P_2O_5, K_2O, S, Zn = Rs. 10.5. 16.2, 7.4, 10.0, and 35.0, respectively.

Uptake of K was highest in wheat grain and straw, followed by mustard. A progressive increase in K levels gradually increased the uptake of K by all the crops. Highest uptake of K corresponded to high-yielding treatments. In all crops, the uptake of K was significantly more than the control treatment with application of at least 60 kg K_2O/ha. No difference in K uptake was noted between the two highest doses, with the exception of mustard seed. Similar results were obtained by Singh and Pathak (2002), and Singh and Singh (2002).

The response in kg grain or seed per kg K_2O showed an increase up to the level of 90 kg K_2O in wheat and mustard while oat responded up to 60 kg K_2O/ha **(Table 3)**. Further increase in the level of K (120 kg K_2O/ha) tended to decrease the K use efficiency over 90 kg K_2O/ha. The comparative magnitude of the response to K varied among the crops as wheat had a 9.7 kg grain response/kg K_2O applied compared to 7.5 kg mustard seed, and 6.0 kg oat grain. A similar increase in KUE with increasing levels of K application was reported by

2009 IPNI Science Award to Dr. J.K. Ladha

The International Plant Nutrition Institute (IPNI) named Dr. J.K. Ladha of the International Rice Research Institute (IRRI) as the winner of the 2009 IPNI Science Award. Dr. Ladha is a senior soil scientist, the coordinator of the Rice-Wheat Consortium in Asia, and representative of IRRI-India. He receives a special plaque plus a monetary award of US$5,000.00 (five thousand dollars).

"Dr. Ladha is a truly outstanding scientist and most deserving of this recognition due to the scope and breadth of his research, training, and extension activities," said Dr. Terry L. Roberts, President of IPNI. "He has made immense contributions to international agriculture through his activities in several Asia countries, on problems across national and regional boundaries."

Born in Gwalior, India, Dr. Ladha earned his Ph.D. in Botany from Banaras Hindu University in 1976. Earlier, he earned his B.Sc. in Biological Sciences in 1971 and his M.Sc. in Botany in 1975 at Jiwaji University in India. He has devoted nearly 30 years of his career to working in the area of integrated resources management with strong emphasis on soil fertility and nutrient management for achieving increased crop yields.

Dr. Ladha's work, in collaboration with many national partners, takes a holistic, systems approach covering various components of agronomic, soil, and water management. He emphasizes farmer-participatory approaches for developing innovative resource-use-efficient alternatives of tillage/crop establishment and fertilizer management strategies.

Dr. J.K Ladha

Dr. Ladha has published extensively in leading peer-reviewed journals and edited several books. He has authored or co-authored 183 research articles in international research journals, 60 articles in proceedings and other books, and has edited or co-edited 11 books.

The IPNI Science Award is intended to recognize outstanding achievements in research, extension, or education, with focus on efficient and effective management of plant nutrients and their positive interaction in fully integrated crop production that enhances yield potential and crop quality. Private or public sector agronomists, soil scientists, and crop scientists from all countries are eligible for nomination. The previous recipients of the IPNI Science Award were Dr. John Ryan of ICARDA in 2008 and Dr. M.S. Aulakh of India in 2007.

More information and nomination forms for the 2010 IPNI Science Award are available from the headquarters or regional offices of the organization, or from the website: www.ipni.net/awards. BC INDIA

Table 2. Effect of K application on uptake (kg/ha) in selected rabi crops.

Crop	Portion	K_2O applied, kg/ha 0	30	60	90	120	CD (p=0.05)
Wheat	Grain	20.2 (0.56)	22.3 (0.59)	27.0 (0.66)	33.9 (0.75)	35.2 (0.78)	2.91 (0.021)
	Straw	94.7 (1.74)	100.1 (1.79)	113.7 (1.87)	130.1 (1.99)	134.0 (2.04)	10.27 (0.026)
Oat	Grain	9.3 (0.51)	11.4 (0.57)	13.9 (0.64)	16.1 (0.69)	17.3 (0.71)	1.57 (0.038)
	Straw	46.3 (1.68)	51.6 (1.73)	58.2 (1.79)	64.2 (1.86)	67.1 (1.89)	4.81 (0.021)
Mustard	Seed	10.1 (0.67)	11.9 (0.73)	14.8 (0.79)	18.8 (0.87)	20.6 (0.92)	1.70 (0.019)
	Stover	71.8 (1.96)	82.6 (2.05)	95.9 (2.14)	112.8 (2.24)	119.5 (2.28)	13.36 (0.030)

Data in parentheses indicate mean content (%) of K.

Table 3. Effect of K application on K use efficiency and apparent recovery in selected rabi crops.

Crop	K_2O applied, kg/ha 30	60	90	120
- - - - - - - - - - - - - K use efficiency (kg produce /kg K_2O) - - - - - - - - - - -				
Wheat	4.6	7.9	9.7	7.4
Oat	5.5	6.0	5.6	4.9
Mustard	5.2	6.3	7.5	6.3
- - - - - - - - - - - - - - - Percent apparent recovery, % - - - - - - - - - - - - - - -				
Wheat	6.8	11.2	15.1	12.5
Oat	7.1	7.7	7.5	6.6
Mustard	6.5	8.0	9.8	8.8

Chaudhary and Roy (1992) and Surekha et al. (2003).

Apparent recovery (%) of K was influenced by K levels with the maximum recovery occurring at 90 kg K_2O/ha, with the exception of oat where a maximum apparent recovery of 7.7% was noted at 60 kg K_2O/ha **(Table 3)**. The ranges of apparent K recovery for these crops results in a ranking which is identical to that for K uptake, wherein wheat > mustard > oat. BC INDIA

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Soil System-Based Approach:
A Tool for Fish Pond Fertilisation

By Abira Banerjee, G.N. Chattopadhyay, and C.E. Boyd

To obtain maximum production of fish from any aquatic environment, it is necessary to maintain the nutrient status of the pond above critical levels in the soil-water system. This study describes an approach that achieves this goal through proper use of fertilisers and manures in fish ponds.

The major objective in application of fertilisers and manures to fish ponds is to encourage the growth and abundance of different fish food organisms, which in turn promotes the growth of fish (Boyd and Tucker, 1998). The aquatic environment supports various communities of living organisms which constitute the biotic load of a pond. Natural productivity is the capacity to increase this biotic load (i.e., all biomass) over time. In fish culture, which depends largely on natural foods, there is normally a close dependence of fish production on the level of primary productivity. This primary productivity in a fish pond indicates the rate of formation of organic matter due to photosynthesis, and is comprised of different groups of living communities, mainly phytoplankton, benthos, and periphyton (Chattopadhyay, 2004). These primary producers either form the natural food item to different phytophagous fishes or give rise to secondary or tertiary organisms as foods of various kinds of fishes with varying food habits **(Figure 1)**. All other environmental factors remaining favorable, nutrient concentrations determine the magnitude of primary production in a water body.

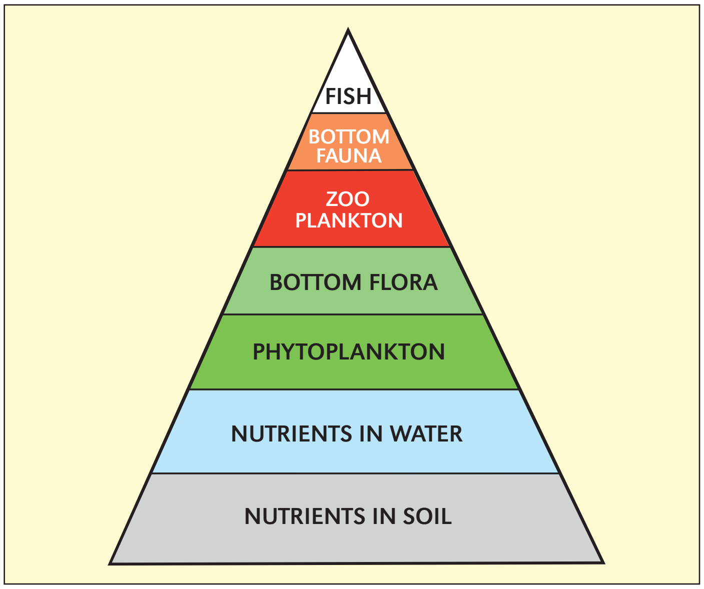

Figure 1. Food chain in fish ponds.

Mortimer and Hickling (1954) established clearly the efficiency of pond fertilizing materials in increasing the productivity of fish ponds. While Saha (1979) reported a four-fold increase in fish yield due to pond fertilisation in India, positive effects of fertilisation on pond productivity have been reported by many other workers from different parts of the world (Hepher, 1962: Dobbins and Boyd, 1976; Mandal and Chattopadhyay, 1992). While fertilisers and manures are applied directly to the soil through which plants derive their nutrients, in aquaculture this effect is brought about through a longer chain consisting of soil-water fertilisation-bacteria-aquatic plants-zoo plankton, and zoo benthos – fish. During the courses of this conversion, plant nutrients undergo various transformations in the soil and water phases. For fixing the rates and manners of use of fertilisers in fish ponds, therefore, due consideration is to be exercised to these echelons of productivity.

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

Maintenance of favorable environmental conditions in fish ponds depends largely on the bottom soil.

Soil System-Based Approach in Fish Pond Fertilisation

Bottom soils play an important role in controlling such nutrient transformations, especially the behaviors of the fertilisers in fish ponds (Chattopadhyay, 2004). The significance of bottom soils in influencing availability of different nutrient elements to primary fish food organisms has been discussed in detail by Boyd and Bowman (1997). Behavior of these nutrients and also maintenance of a favorable environmental condition in any pond are controlled largely by the bottom soil of the pond where a series of chemical and biochemical reactions continuously take place. These reactions influence not only the release of inherent nutrients from soil to the water phase, but also the transformation of added fertilisers in the ponds. Wudtisin and Boyd, (2005) discussed considerable variations in the results of pond fertilisation under different locations and

Table 1. Average productivity of fish ponds in red and lateritic soil zones under two different fertilisation programmes.

Parameter	Traditional fertilisation	Soil system-based fertilisation	Average increment, %
Gross primary production (Mean), mg C/m^3/hr	175 to 600 (371)	251 to 665 (480)	29.3
Net primary production (Mean), mg C/m^3/hr	75 to 425 (214)	100 to 525 (295)	37.8
Estimated fish yield (Mean), t/ha	0.92 to 2.56 (1.74)	1.25 to 3.00 (2.12)	22.1

Chattopadhyay and Banerjee, 2005.

these were attributed to variations in the nature and properties of bottom soils. In view of the wide variations in the properties of bottom soils situated in different soil zones and their influence on pond productivity, it appears to be appropriate to develop a soil system-based nutrient management approach for different fish ponds. While working with fish ponds situated in red and latertic soil zones, Banerjee and Chattopadhyay (2004) studied the nature and properties of large numbers of fish pond soils with relation to their primary productivity of water and identified the major soil factors responsible for variations in gross production of primary fish food organisms in such ponds **(Figure 2)**.

Based on the information on the relative importance and status of the productivity-limiting plant nutrients in such pond soils, a soil system-based pond fertilisation programme was developed. This approach appeared to be more efficient than the traditional method of fertiliser application in fish ponds since it took into consideration the inherent nutrient supplying capacity of the pond soils along with other relevant properties of the ecosystem **(Table 1)**.

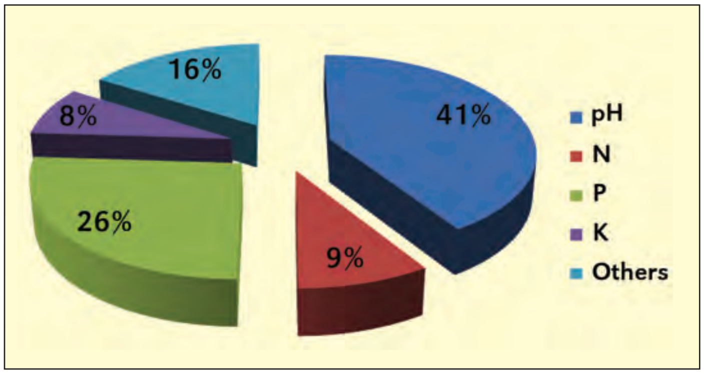

Figure 2. Percent contribution of different soil properties on gross primary productivity of fish pond water in red and lateritic soil zones.

Use of Critical Levels of Nutrients for Optimising Fertiliser Rates in Aquaculture

Fertilisation rates for agricultural crops are commonly determined from the availability of nutrients in the soils. In view of the importance of bottom soils in influencing the efficiency levels of different pond fertilising materials, it should be possible to apply the approach used in agriculture to assess the relationship between bottom soil nutrient concentrations and production of primary fish food organisms. This will also help to determine the requirements of different fertilisers for achieving economic benefits from fish pond fertilisation under different soil zones. After the initial work of Cate and Nelson (1965), a large number of studies throughout the world determined the critical levels of various plant nutrients for different crops under varying soil conditions. Recently, Banerjee et al., (2009) reported a systematic study to adopt this principle in determining the critical levels of three major plant nutrients viz. N, P, and K in fish pond soils of red and lateritic soil zones and to assess the threshold levels of pond fertilisers required for attaining these critical limits.

Bottom soils were collected from different fish ponds situated in typical red and lateritic soil zones of West Bengal, India. To represent each pond, one kg of the 80 mesh sieved pond soil sample was taken into each of nine aquariums and the soils were incubated with 20 L of de-ionized water for 15 days to develop a semi-aerobic condition that simulated a typical fish pond. To determine the critical level of any nutrient, the pond soils were treated at different doses. For example, P was used at 0, 75, and 150 mg/kg/yr doses, split into 10 monthly applications. Along with the nutrient under study, the samples also received uniform doses of N and K, split as before. This was done to prevent any possibility of these two primary nutrients behaving as productivity-limiting factors. Each of the treatments were replicated three times and incubated under illuminated conditions. Soil samples were collected at weekly intervals from each of the aquariums for 3 weeks and were analyzed for gross primary productivity (GPP) of water and available P in soil. Similar studies were carried out for determining the critical limits of the other two primary nutrients.

The mean values of GPP of water, as well as availability of the particular nutrient in the soil, were monitored during the period of incubation under each soil-water system with different doses of fertilization for assessment of critical levels of available soil nutrients. For this purpose, Bray's percent yield (BPY) concept (Bray, 1948) was modified slightly by adopting the following formula.

$$\text{BPY} = \frac{\text{GPP with added nutrient - GPP with no added nutrient}}{\text{GPP with added nutrient}} \times 100$$

The obtained BPY values for different soil-water systems were then used for graphical determination of critical levels of the available nutrient in fish pond soils by following the principle of Cate and Nelson (1965). The studies showed the critical levels of the three nutrients to be 200, 13, and 80 mg/kg soil for N, P, and K, respectively, in red and lateritic soil zones. The necessary amount of N, P, and K fertilisers should be applied for maintaining the observed critical levels of these three nutrients in fish pond soils.

To test the effects of maintaining the critical levels of the major nutrients on productivity levels, on-farm trials were carried out in 18 ponds located on 9 fish farms representing different red and lateritic soil zones. The mean effect of the three pond productivity-limiting nutrients on GPP of pond water are presented in **Figure 3**. Mean available P status attained its critical level in pond soils during September, after

Table 2. Estimated economic return from the inputs used in the soil system-based pond management programme.

	Traditional fertilisation	Soil system-based fertilisation
Inputs	---------- Costs, Rs./ha ----------	
N fertiliser	1,000	2,000
P fertiliser	2,500	5,000
K fertiliser	-	498
Lime	1,280	640
Total cost	4,780 A	8,138 B
Return	---------- Income ----------	
Fish yield, kg/ha	1,758	2,153
Gross return, Rs.30/kg	52,740	64,590
Net return over fertilisation cost, Rs./ha	47,960 C	56,452 D
Added cost due to soil system-based fertilisation, Rs./ha		3,358 (A-B
Added benefit due to soil system-based fertilisation, Rs./ha		8,492 (C-D)
Benefit-to-cost ratio	2.53	

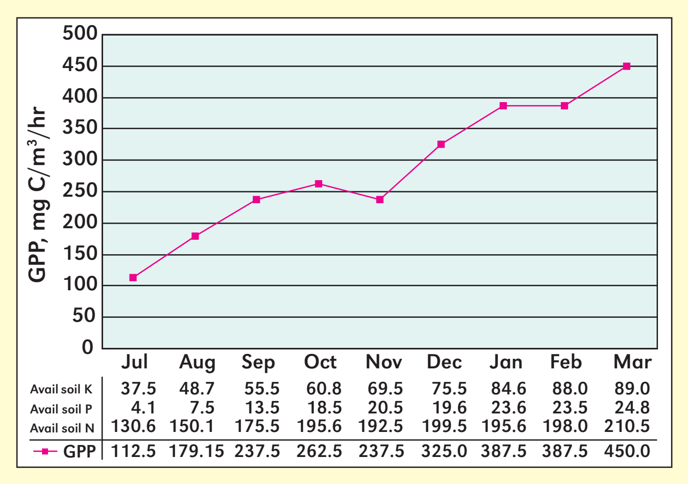

Figure 3. Variation in Gross Primary Productivity due to soil nutrient supply during the second year of study (Banerjee, 2005).

Even with added input cost, an improved nutrient management programme can have a very favorable benefit.

which the GPP values recorded an increasing trend. However, the availability of N and K were below this threshold limit during this period. Both of the nutrients neared the critical limits during November-December and GPP values exhibited a sharp increase owing to optimal presence of all the three productivity-limiting nutrients in the pond environment.

An approximate assessment of additional economic return from the proposed soil system-based pond fertilisation, using local rates for different inputs and outputs, is presented in **Table 2**. Adoption of the proposed nutrient management programme required an extra input cost of Rs.3,358/ha. However, this helped to produce an additional 395 kg fish/ha which under a conservative price of Rs.30/kg could fetch an additional income of Rs.8,492/ha of pond area. This resulted in an encouraging benefit-to-cost ratio of 2.53, supporting the developed this soil system-based pond productivity management programme.

All these results show that a soil system-based approach to pond management involving identification of major productivity-limiting soil factors, determination of critical levels for relevant plant nutrients, and maintenance of those nutrients at adequate levels, may be considered as an effective proposition for increasing the productivity of fish ponds and improving the response of fertilisers in the aquatic ecosystem. BC INDIA

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In Memoriam: Dr. Norman Borlaug, 1914-2009

The International Plant Nutrition Institute (IPNI) Board of Directors issued a brief statement honoring the legacy of Dr. Norman Borlaug, who passed away on September 12 in Dallas, Texas, at the age of 95.

The message of the IPNI Board of Directors states: *We join with millions of people around the world in expressing appreciation and admiration for the great achievements of Dr. Norman Borlaug. His dedication to science in agriculture is responsible for improving the lives of individuals around the world over the past 50 years and into the future. In an amazing journey from his Iowa farm roots to world recognition as a Nobel Peace Prize laureate, he never lost sight of the importance of global food security and the power of science through agriculture. Dr. Borlaug was considered by many as the father of the 'Green Revolution' as his early work in plant breeding led to great increases in harvests of cereal crops in Mexico, India, Pakistan, and other countries. His phenomenal success in breeding high-yielding varieties of wheat, rice, and other crops evolved into broader initiatives in training young agricultural scientists, educating audiences around the globe, and furthering important humanitarian causes. The International Plant Nutrition Institute extends its condolences to the Borlaug family and to his many friends and colleagues. While we are saddened by the loss of this innovative scientist and beloved leader, we believe his vision and accomplishments will serve as inspiration to future generations to continue the quest for world food security.*


Photo source: AgriLife

Dr. Borlaug in field plots.

"Dr. Borlaug was one of those rare individuals who made the most of his fame and influence to champion the cause of applying science for humanitarian benefits," noted IPNI President Dr. Terry Roberts. "He recognized the role of fertilizer in producing the world's food and took every opportunity to remind policymakers and the public that fertilizer is a critical component of global food security. He was just as much at ease sharing that message with a small farmer as he was with a scientist or the leader of a country. Dr. Borlaug was truly a unique man who did much for mankind."

The Nobel committee honored Dr. Borlaug in 1970, when he was 56 years old, for his work in developing high-yield crop varieties and bringing other agricultural innovations to the developing world. Many experts credit the Green Revolution with averting global famine during the second half of the 20th century and saving perhaps 1 billion lives. World food production more than doubled between 1960 and 1990, and grain yields in Pakistan and India more than quadrupled.

Considered equal parts scientist and humanitarian, Dr. Borlaug realized improved crop varieties were just part of the answer and pressed governments for farmer-friendly economic policies and improved infrastructure to make markets accessible. A 2006 book about him is titled "The Man Who Fed the World."


Photo source: AgriLife

Dr. Norman Borlaug

Dr. Borlaug was born March 25, 1914, on a farm near Cresco, Iowa. He was educated through the eighth grade in a one-room schoolhouse. He left home during the Great Depression to study at the University of Minnesota. He worked briefly for the U.S. Forest Service, then returned to the university for a doctoral degree in plant pathology. Dr. Borlaug worked as a microbiologist in industry for a short time, then joined the Rockefeller Foundation. Between 1944 and 1960, he dedicated himself to increasing Mexico's wheat production. He developed high-yielding, short-strawed, disease resistant varieties that thrived in Mexico, and later in India, Pakistan, Turkey, and other countries as well. In 1963, he was named head of the newly formed International Maize and Wheat Improvement Center (CIMMYT) in Mexico, where he trained thousands of young scientists. His plant-breeding methods were also successful in developing improved lines of rice and other crops.


Bringing the Green revolution to Africa was one of Dr. Borlaug's goals.

After retiring as head of the center in 1979, Dr. Borlaug turned to university teaching, first at Cornell University and then at Texas A&M, which presented him with an honorary doctorate in December 2007. In 1986, Dr. Borlaug established the Des Moines, Iowa-based World Food Prize, a $250,000 award given each year to a person whose work improves the world's food supply. He also helped found and served as president of the Sasakawa Africa Foundation, an organization intended to introduce the Green Revolution to sub-Saharan Africa.

In July 2007, Dr. Borlaug received the Congressional Gold Medal, the highest honor given by Congress.

A public memorial at Texas A&M University on October 6, 2009, celebrated the life and work of Dr. Borlaug. About 1,000 people attended the service. To learn more about his vision and legacy, visit the website of the Norman Borlaug Institute for International Agriculture: >http://borlaug.tamu.edu<.

Nutrient Management to Improve Maize Productivity in Tamil Nadu

By P. Malarvizhi, S. Thiyageshwari, M. Paramasivan, R. Geetha, V. Kasthuri Thilagam, T. Nagendra Rao, and T. Satyanarayana

Maize and maize-based cropping systems are becoming important for food and nutritional security in Tamil Nadu. A systematic approach to soil fertility evaluation determined common nutrient deficiencies on soils in Tamil Nadu and established guidelines for nutrient application rates to optimise crop production and profitability.

Maize is the third most important cereal crop in India after rice and wheat and is cultivated on 8.11 million (M) ha. Total maize production is 19.77 M t, with an average yield of 2,435 kg/ha in 2007-08 (DMR, 2008). Maize is a non-traditional crop in Tamil Nadu, cultivated on 0.18 M ha, with a production of 0.29 M t and an average productivity of 1,552 kg/ha, or only 64% of the national average (Season and Crop Report, 2005). This yield gap is mainly due to inadequate and imbalanced fertilisation and lack of distinct fertiliser recommendations for the various varieties and hybrids grown. There is significant opportunity for maximising maize yields to meet the ever-increasing feed grain demand by the growing livestock industry in the state.

This study's systematic approach to assessing plant nutrient deficiencies involved the determination of prevailing soil nutrient disorders through laboratory sorption studies and greenhouse experiments prior to conducting field experiments (Portch and Hunter, 2002). There is flexibility in this approach for repeating relatively inexpensive greenhouse experiments in case there is need for further clarification of nutrient disorders detected. Field experiments conducted in the final phase enable confirmation of screening results from the laboratory and greenhouse studies and helps in generating optimum nutrient recommendations for the test crop under various field situations.

Nutrient optimisation strategy is needed to increase maize yields.

Greenhouse experiments indicated that N, P, K, and Zn would be the most limiting nutrients.

Experiments were conducted on seven different soil series representing dominant soil types where maize is grown. These included the Irugur (Igr) series in Coimbatore district (sandy clay loam, Typic Haplustalf), Palaviduthi (Pvd) series in Dindigul district (sandy clay loam, Typic Rhodustalf), Palladam (Pld) series in Coimbatore district (sandy clay loam,

Table 1. Response of CO 29 sorghum in greenhouse nutrient survey.

	------------- Dry matter yield, g/pot -------------							
Treatments	Igr	Tlk	Pvd	Pld	Plm	Myk	Mdk	Mean
ONT	1.94 (100)	2.48 (100)	1.98 (100)	1.99 (100)	2.51 (100)	2.24 (100)	2.03 (100)	2.17 (100)
ONT-N	1.23 (63)	1.32 (53)	1.13 (57)	1.13 (57)	1.36 (54)	1.33 (59)	1.12 (55)	1.23 (57)
ONT-P	1.46 (75)	1.47 (59)	1.22 (62)	1.23 (62)	1.43 (57)	1.45 (65)	1.2 (59)	1.35 (63)
ONT-K	1.62 (84)	1.76 (71)	1.38 (70)	1.33 (67)	1.74 (69)	1.64 (73)	1.31 (65)	1.54 (72)
ONT-Zn	1.25 (64)	1.85 (75)	1.52 (77)	1.54 (77)	1.88 (75)	1.75 (78)	1.58 (78)	1.62 (75)
Control	0.52 (27)	1.02 (41)	0.59 (30)	0.68 (34)	1.99 (43)	0.92 (41)	0.75 (37)	0.92 (36)
SEd	0.06	0.07	0.06	0.06	0.1	0.09	0.08	
CD ($p = 0.05$)	0.12	0.13	0.12	0.11	0.2	0.19	0.17	

Abbreviations: N = nitrogen; P = phosphorus; K = potassium; S = sulphur; C = carbon; Ca = calcium; Mg = magnesium; Zn = zinc; Cu = copper; Mn = manganese; Fe = iron; ONT = Optimum Nutrient Treatment; SR = State Recommendation; CD = Critical Difference, equivalent to Least Significant Difference; SEd = Standard Error of the Difference.

Table 2. Fertilisation rates of the Optimum (ONT) and State recommendation (SR) treatments used at each experimental site.

	$N\text{-}P_2O_5\text{-}K_2O\text{-}Zn$, kg/ha						
Treatments	Igr	Tlk	Pvd	Pld	Plm	Myk	Mdk
ONT	200-54-80-8	200-76-75-11	200-76-88-7.4	200-80-85-6	200-60-25-10	200-64-48-4.8	200-70-152-9.6
SR	135-62.5-50-5.5	135-62.5-50-5.5	135-62.5-50-5.5	135-62.5-50-5.5	135-62.5-50-5.5	135-62.5-50-5.5	135-62.5-50-5.5

Table 3. Grain yield of maize in different soil series of Tamil Nadu.

	Grain yield, kg/ha							
Treatments	Igr	Tlk	Pvd	Pld	Plm	Myk	Mdk	Mean over locations
ONT	7,120	7,247	7,182	7,284	7,209	7,265	7,210	7,217
ONT-N	3,125	3,200	3,150	3,252	3,498	3,218	3,163	3,229
ONT-P	3,640	3,764	3,720	3,822	4,085	3,782	3,740	3,793
ONT-K	3,887	3,930	3,873	3,975	3,546	3,948	3,926	3,869
ONT-Zn	5,675	5,840	5,748	5,850	5,952	5,858	5,785	5,815
ONT (125% N)	7,805	7,987	7,712	7,814	8,147	8,005	7,908	7,911
SR	5,895	6,058	5,920	6,022	6,110	6,076	5,975	6,008
Control	2,598	2,786	2,667	2,769	2,886	2,804	2,698	2,744
SEd	321	328	109	329	96	118	115	
CD (p = 0.05)	664	677	224	679	197	244	237	

Table 4. Unit cost of inputs and produce.

S. No.	Particulars	Units	Cost (Rupees)
	Inputs		
1.	Maize seed (COHM -5)	1 kg	70
2.	Urea	1 kg	5
3.	Super phosphate	1 kg	4
4.	Muriate of potash	1 kg	4
5.	Zinc sulphate	1 kg	26
6.	Atrazine	1 kg	240
	Labour Wages		
7.	A type (Man)	8 hrs/day	100
8.	B type (Woman)	8 hrs/day	50
	Produce		
9.	Maize grain	1 quintal	700
10.	Stover	1 tonne	300

Lithic Haplustept), Thulukkanur (Tlk) series in Salem district (Gravely sandy loam, Typic Haplustept), Mayamankuruchi (Myk) series in Tirunelveli district (Clay, Typic Haplustept), Peelamedu (Plm) series in Perambalur district (Clay, Typic Haplustert), and Madhukur (Mdk) series in Perambalur district (sandy clay loam, Udic Haplustalf). The results of the initial soil analyses indicated that the Igr, Tlk, Pvd, and Pld soil series had an alkaline pH and were non-saline in nature. Organic C and available N, P, and Zn were low in most of the soil series. Secondary nutrients (Ca, Mg, and S) were sufficient and micronutrients like Cu, Mn, and Fe were above the critical limits.

Nutrient sorption studies were carried out by adding a specific amount of the plant nutrient in solution to a specific volume of soil and allowing it to incubate for 72 hours in a dust free environment. The air dried sample was then analysed for the respective nutrient elements. Sorption curves were drawn for each nutrient by plotting the amount of nutrient extracted on the Y axis against the amount of nutrient added on the X axis. The optimum nutrient treatment for the greenhouse experiment was defined for each experimental soil based on the nutrient fixation or complexation characteristics. The greenhouse experiments were carried out using sorghum (var. CO 29) as the test crop (Portch and Hunter, 2002).

Nutrient sorption and greenhouse experiments indicated that N, P, K, and Zn would be the most limiting nutrients for maize growth. Use of the optimum nutrient treatment resulted in a dry matter yield which varied from 1.94 to 2.51 g/pot, with an average of 2.17 g/pot across the different soil series **(Table 1)**. Relative yields were 57, 63, 71, and 75% of the optimum when N, P, K, and Zn were omitted. No significant yield reductions were noticed with other nutrients, indicating that only N, P, K, and Zn required further investigation to establish the nutrient requirement of maize under field conditions.

The data above were used in subsequent field experiments conducted at different locations representing all seven soil series. The fertiliser rates were calculated to bring the desired level of each nutrient up to the optimum for crop growth **(Table 2)**. Four rates of N, P, and K in selected combinations, along with a single rate of Zn, were tested using three replications in a randomised block design. In this summary, only the optimum rate is shown in the results presented. Maize yields of up to 7.2 t/ha were obtained, averaged over the seven different soil series, with the application of N, P_2O_5, K_2O, and Zn at the rates of 200, 69, 79, and 8 kg/ha, respectively **(Table 3)**. Skipping any of these nutrients from the optimum dose drastically impacted crop yields, proving that those four nutrients were crucial to maize production at these locations.

The grain yield of maize obtained with the ONT treatment was 7.2 t/ha as compared to 6 t/ha under the SR **(Table 3)**, a yield advantage of 20% or more at 6 out of 7 soil series. Similarly, a grain yield of 7.9 t/ha with the ONT (125% N) treatment provided a 32% yield advantage over the SR **(Table 3)**. This latter result indicates that the maize crops responded to additional levels of N applications over the initial ONT recommendations and there is a need to further study the yield advantage with additional levels of N.

Economic comparisons were calculated based on the cost of crop inputs, labour, and the value of harvested grain and stover **(Table 4)**. The optimum nutrient levels developed using Agro Services International (ASI) method (Portch and Hunter, 2002) for hybrid maize proved beneficial to farmers as this approach resulted in a calculated net income of Rs.35,000/ha, versus

Optimum treatments produced maize grain yields of 7.2 t/ha, compared to 6 t/ha with State Recommendation rates.

Rs.23,200/ha with the SR. This approach further resulted in a benefit-to-cost ratio of 2.52 with ONT, versus 2.11 obtained with the adoption of the SR.

The outcome of this study on optimising nutrient needs using an established systematic approach in different benchmark soils of Tamil Nadu will help to increase maize production and identify the response of major, secondary, and micronutrients. Further refinement of actual nutrient application rates in field trials ultimately leads to the fertiliser recommendations which farmers of Tamil Nadu can use to achieve maximum economic yield. BC INDIA

Dr. Malarvizhi is Professor and Dr. Thiyageshwari is Associate Professor of Soil Science, TNAU. Mr. Paramasivan, Ms. Geetha, and Ms. Kasthuri Thilagam assisted in the project as research scholars. Dr. Nagendra Rao is former Deputy Director and Dr. Satyanarayana is current Deputy Director, IPNI India Programme, South India and Sri Lanka; e-mail: tsatya@ipni.net.

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On-farm Evaluation of SSNM in Pearlmillet-Based Cropping Systems on Alluvial Soils

By B.S. Dwivedi, Dhyan Singh, K.N. Tiwari, A. Swarup, M.C. Meena, K. Majumdar, K.S. Yadav and R.L. Yadav

Results from on-farm experiments comparing soil test-based site-specific nutrient management (SSNM) with other fertiliser practices in pearlmillet-wheat and pearlmillet-mustard cropping systems revealed large yield and economic advantages from soil analysis. Macronutrient, secondary nutrient, and micronutrient supplementation was required to optimise yields and profits.

Asian soils are generally low in organic matter, and have consistently been depleted of nutrients due to continuous cropping (Yadvinder-Singh et. al., 2007). The problem of soil fertility depletion in India is a result of intensive cultivation and unbalanced and inadequate fertiliser recommendations. As a consequence, the incidence of multinutrient deficiencies of varying nature and their expansion in different soils has recently been documented (Dwivedi et al., 2006). Development of SSNM options and their promotion appears to be the only pragmatic way to address the already emerged complex soil fertility problems, and enhance nutrient use efficiency, crop productivity, and profits. To fully evaluate the impact of SSNM recommendations we initiated 14 farmer-managed on-farm experiments on alluvial soils of the IGPR.

Fourteen on-farm experiments, 8 with pearlmillet-wheat and 6 with pearlmillet-mustard cropping system, were conducted during 2007-08 near the village of Lohtaki in Gurgaon district, India. Lohtaki was selected as it represented the semi-arid climate of the Upper Gangetic Plain transect of the IGPR, with alluvium-derived deep and well-drained soils (Typic Ustochrept) that had loamy sand to sandy loam texture. Shallow to deep tube wells were the source of irrigation, and the ground water quality was satisfactory and suitable for all kinds of field crops. For each experiment, a half-acre (2,000 m^2) farm area was divided into 7 strips to impose 7 fertiliser treatments including: T_1: SSNM; T_2: Fertiliser NPK recommended for a pre-set yield target as per AICRP-STCR's (All India Coordinated Research Project on Soil Test Crop Response Correlations) yield adjustment equations (TY); T_3: TY+secondary & micronutrients (TY+Micro); T_4: State ad-hoc recommendation (SR); T_5: SR+K; T_6: Farmer's fertiliser practice (FFP)+K; and T_7: FFP. Fertiliser rates in SSNM and TY varied for different experiments in accordance with soil test values. Under SSNM, fertilizer N was applied at 150 kg/ha to pearlmillet or wheat, and at 120 kg/ha to mustard. Fertilizer P_2O_5 and K_2O rates were 60 and 90 kg/ha, respectively for all crops on soils that were analysed medium in P and K fertility status (i.e. 10 to 25 kg available P/ha and 121 to 280 kg available K/ha), and these rates were either increased or decreased by 25 to 33% when soil P or K content was smaller or greater than the medium fertility thresholds. In T_1 and T_3, fertilizer S, Zn and B were applied only on the sites that were deficient in these nutrients. Averaged across the experimental sites, fertiliser $N+P_2O_5+K_2O$ rates for SSNM were 150+62+105 kg/ha in pearlmillet, 150+58+75 kg/ha in wheat and 120+60+100 kg/ha in mustard, and the corresponding rates for TY in these crops were 120+30+62, 192+34+77, and 122+69+114 kg/ha, respectively. On the other hand, fertiliser rates for FFP and SR remained uniform across the experiments. FFP, as determined on the basis of diagnostic survey of Lohtaki and neighboring villages, received 60 kg N/ha alone in pearlmillet, 80 kg N + 62 kg P_2O_5/ha in wheat and 60 kg N + 60 kg P_2O_5/ha in mustard. The SRs for these crops were 125 kg N + 62 kg P_2O_5 + 10 kg $ZnSO_4$/ha, 150 kg N + 60 kg P_2O_5 + 30 kg K_2O/ha and 80 kg N + 30 P_2O_5 + 250 kg gypsum/ha, respectively. In all crops one-third of total N, half of total K, and the entire quantity of P, S, Zn, and B as per treatment was applied as basal dressing

Abbreviations for this article: SSNM = site-specific nutrient management; EC = electrical conductivity; OC = organic carbon; N = nitrogen; P = phosphorus; K = potassium; S = sulphur; Zn = zinc; B = boron; Fe = iron; Mn = manganese; Cu = copper; IGPR = Indo-Gangetic Plain Region; HYVs = high yielding varieties; CD = Critical Difference, equivalent to Least Significant Difference.

Comparing field performance of hybrid pearlmillet under SSNM vs. FFP.

Visiting the wheat and mustard experiments at Lohtaki, Gurgaon; Dr. Adrian M. Johnston and Dr. Tiwari are shown in the center.

Table 1. Initial soil fertility status of fourteen on-farm experiment sites.

Parameters	Min	Max	Mean	Remarks
pH	7.4	8.1	7.8	Mildly alkaline
EC, dS/m	0.06	0.10	0.08	Non-saline
Org. C, %	0.19	0.35	0.25	All sites deficient in N
Avail P, kg/ha	14.6	56.8	26.1	9 sites deficient in P
Avail K, kg/ha	43	310	121	13 sites deficient in K
Avail S, kg/ha	12.2	47.5	26.6	8 sites deficient in S
Avail Zn, mg/kg	0.61	1.20	0.87	8 sites deficient in Zn
Avail Fe, mg/kg	6.22	10.75	8.55	No deficiency
Avail Mn, mg/kg	0.35	0.58	0.47	No deficiency
Avail Cu, mg/kg	8.45	11.78	10.0	No deficiency
Avail B, mg/kg	0.39	1.44	0.89	3 sites deficient in B
Texture	Loamy sand to Sandy loam			

Mustard plants had up to 103 seed pods per branch under SSNM.

at the time of sowing. The remaining amount of N and K was top-dressed in two and one splits, respectively.

In the pearlmillet-wheat system, S, Zn, and B were applied to pearlmillet only and wheat drew residual benefit of these nutrients. In the other cropping system, however, winter mustard also received S in SSNM, TY+Micro, SR, and SR+K treatments. The harvested biomass was sun-dried and yields recorded at constant moisture content.

Initial and post-harvest soil samples (0 to 15 cm depth) were collected from all plots, and analysed for available nutrient content (Page et al., 1982). For comparison of monetary returns under different fertiliser management options, the cost (per kg) of fertiliser N, P_2O_5, K_2O, S, Zn, and B was taken as Indian Rupees (Rs.) (US$1 = Rs.42) 10.50, 16.22, 7.43, 10.00, 35.00 and 25.00, respectively. The price (per tonne) of pearlmillet, wheat, and mustard grain was Rs.6,100, 10,400 and 18,600, and that of straw/stover was Rs.1,000, 2,000 and 400, respectively.

Table 2. Response of pearlmillet-wheat system to fertiliser options (8 on-farm experiments averaged).

	Grain yield, t/ha			Net return over FFP, Rs./ha		
Treatment	Pearl-millet	Wheat	System (PMEY[1])	Pearl-millet	Wheat	System (PMEY[1])
SSNM	4.12	5.61	13.69	10,468	25,389	35,856
TY	3.65	4.88	11.97	10,151	16,406	26,558
TY+Micro	3.93	5.27	12.91	10,789	20,766	31,556
SR	3.10	4.03	9.97	5,934	6,652	12,586
SR+K	3.68	4.83	11.92	9,649	16,126	25,775
FFP+K	2.60	3.78	9.05	2,850	4,034	6,885
FFP	2.21	3.40	8.00	-	-	-
CD** (p = 0.05)	0.18	0.15	0.25	-	-	-

[1] Pearlmillet equivalent yield.
**Critical difference where on-farm sites for a cropping system were taken as replicates for the ANOVA.

In order to compare the annual yield responses to fertiliser options, pearlmillet equivalent yield (PMEY) of the cropping systems was computed as:

$$PMEY = Y_{PM} + \{(Y_{W\ or\ M} \times P_{W\ or\ M})/P_{PM}\}$$

where Y_{PM} and $Y_{W\ or\ M}$ are the grain yields of pearlmillet and wheat or mustard expressed as t/ha, and $_{PPM}$ and $P_{W\ or\ M}$ the price of pearlmillet and wheat or mustard grain expressed as Rs./t.

The initial soil fertility status of the experimental sites presented in **Table 1** revealed that the soils were mildly alkaline (pH 7.4 to 8.1) and non-saline (EC 0.06 to 0.10 dS/m). All the soils were deficient in N, as soil organic C content varied from 0.19 to 0.35%. Potassium deficiency was the next important soil fertility constraint, for 13 out of 14 sites containing available K in the range of 43 to 165 kg/ha representing the fertilizer responsive category. Nine sites were deficient in P, 8 each in S and Zn, and 3 sites had very low (< 0.5 mg/kg) B content.

Pearlmillet grain yield, averaged across the 8 on-farm experiments, varied from 2.21 t/ha under FFP to as high as 4.12 t/ha under SSNM **(Table 2)**. The SSNM treatment wherein nutrients were applied not only to meet the crop demands, but also to avoid any mining of the soil, out-yielded the targeted yield (TY) treatment that received NPK as per AICRP-STCR's yield adjustment equations. The mean yield difference of 0.47 t/ha between these two treatments was partly ascribed to inclusion of secondary and micronutrients (S, Zn, and B) in SSNM. Inclusion of 45 kg K_2O/ha alone in FFP produced an additional grain yield of 0.39 t/ha; the benefit of K fertilisation was, however, greater (0.58 t/ha) when SR was supplemented with fertiliser K. Surprisingly, the SR for a K-exhaustive crop like pearlmillet was devoid of K, causing not only a substantial yield loss year after year, but also an excessive mining of already depleted native K reserves.

In wheat, SSNM out-yielded FFP and SR by an average of 2.21 and 1.58 t/ha, respectively, establishing again the inadequacy of the SR in exploiting the yield potential of modern cultivars under this high productivity transect of the IGPR **(Table 2)**. These results corroborate the findings of multi-locational on-station experiments with rice-wheat and

Table 3. Response of pearlmillet- mustard system to fertiliser options (6 on-farm experiments averaged).

Treatment	Grain yield (t/ha) Pearl-millet	Mustard	System (PMEY*)	Net return over FFP, Rs./ha Pearl-millet	Mustard	System (PMEY*)
SSNM	4.05	2.88	12.83	8,797	23,549	32,346
TY	3.50	2.45	10.96	7,683	15,484	23,167
TY+Micro	3.83	2.76	12.23	8,900	20,890	29,790
SR	3.08	1.93	8.96	4,176	6,890	11,066
SR+K	3.52	2.18	10.17	7,239	11,417	18,656
FFP+K	2.73	1.71	7.94	2,423	2,253	4,676
FFP	2.36	1.56	7.12	-	-	-
CD** (p=0.05)	0.16	0.10	0.30	-	-	-

*Pearlmillet equivalent yield.
**Critical difference where on-farm sites for a cropping system were taken as replicates for the ANOVA.

rice-rice cropping systems, which amply showed the possibility of doubling current productivity levels through adoption of improved SSNM options (Tiwari et al., 2006). An increase in K application rate from 30 kg K_2O/ha in the SR to 90 kg K_2O/ha in SR+K produced an additional wheat grain yield of 0.81 t/ha which simply suggested that (i) a lower fertiliser K rate would not suffice, and (ii) high productivity systems have to be necessarily supplemented with relatively higher K rates. The carryover effect of S and micronutrients accounted for a 0.39 t/ha wheat grain yield increase, which was greater compared with the direct effect (0.28 t/ha) recorded in pearlmillet.

Annual productivity of the pearlmillet-wheat system computed as PMEY, revealed a yield increase (over FFP) ranging from 1.05 t/ha in FFP+K to 5.69 t/ha in SSNM, which corresponded to a response range of 13 to 71% over FFP **(Table 2)**.

The treatment effects on pearlmillet in the rotation with mustard were similar to those noticed in the pearlmillet-wheat system, although the grain yield, averaged across 6 experiments, ranged between 2.36 and 4.05 t/ha, with the lowest in FFP and the highest in SSNM **(Table 3)**. Inclusion of S and micronutrients (Zn and B) with the TY treatment brought a yield increase of 0.33 t/ha. The SR+K treatment (SR supplemented with K fertiliser at 1.5 times the P_2O_5 rate), produced an average additional yield of 0.58 t/ha over the SR, and the yield levels were similar to the TY treatment. Yield responses over FFP were the highest for the SSNM (71%), followed by TY+Micro (62%), and SR+K or TY (48 to 49%).

Mustard grain yield under SSNM (that included on average 120 kg N + 60 kg P_2O_5 + 100 kg K_2O + 40 kg S/ha along with carryover of S, Zn, and B applied to the preceding crop) ranged between 2.76 and 3.11 t/ha in different experiments with a mean of 2.88 t/ha, which was 83 to 92% (mean 85%) greater than that recorded with the FFP **(Table 3)**. Yield gain in terms of percent response under SSNM or TY+Micro over FFP was relatively greater in mustard than that in pearlmillet, possibly due to S input in the former cases and not in the FFP. Although mustard is not known to be as responsive to fertiliser K as wheat (Tiwari and Nigam, 1994), inclusion of K in FFP or SR increased its yield by an average of 0.15 to 0.25 t/ha in these studies, possibly due to extremely low K content of soils.

In PMEY also, yield differences between SR+K and SR were greater compared with those between FFP+K and FFP, indicating that a crop well-fertilised with NP (and preferably other deficient nutrients) would respond better to fertiliser K compared with a crop receiving N alone or N and P at a lower rate as in case of FFP **(Table 3)**.

In the pearlmillet-wheat system, net returns for pearlmillet under SSNM, TY, and TY+Micro (Rs. 10,151 to 10,789/ha) did not differ appreciably, but the same were invariably greater compared with the net returns recorded under other treatments (Rs. 2,850 to 9,649/ha) **(Table 2)**. The treatment differences were more spectacular for subsequent wheat yields, wherein SSNM gave highest net returns (Rs. 25,389/ha), followed by TY+Micro (Rs. 20,766/ha), and TY (Rs. 16,406/ha). Total annual net returns under different fertiliser options followed a trend similar to that in wheat, and the SSNM treatment generated highest net returns of Rs. 35,856/ha.

In the pearlmillet-mustard system, soil-test based fertiliser use (SSNM, TY, or TY+Micro) resulted in higher net returns (Rs. 7,683 to 8,900/ha) compared with other options for the pearlmillet crop **(Table 3)**. In the subsequent mustard crop, however, SSNM with a net return of Rs. 23,549/ha, was distinctly superior to other treatments. Return per Rupee invested in fertiliser was naturally higher in mustard, owing to the residual benefit of S and micronutrients. Annual net returns over FFP, averaged across the experiments, were also the highest under SSNM (Rs. 32,346/ha), followed by TY+Micro (Rs. 29,790/ha).

These project results illustrate the significance that soil test-based SSNM can have on crop yields and net returns without detriment to soil fertility. Further, the conventional recommendations proved suboptimal and insufficient for HYVs under intensive cropping systems, thus necessitating not only for their upward revision but also for inclusion of secondary and micronutrients. In the cereal-based cropping systems with K-exhaustive crops like hybrid pearlmillet, emphasis has to be laid on K application (of course along with other nutrients) at appropriate rates that may range between 60 and 120 kg/ha/crop depending on available K status of the soil. Substantial yield responses (direct as well as residual) to secondary and micronutrients (S, Zn, and B in the present studies) suggested that balanced fertiliser use no longer meant application of NP or NPK, but should include all nutrients that are deficient at a particular site.

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Maximising Yield of Cowpea through Soil Test-Based Nutrient Application in Terai Alluvial Soils

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

Highest cowpea yields were obtained when N, P, and K were applied at rates 25% higher than the soil test-based optimum rate, keeping S, Zn, and B at their optimum levels. Omission of all the limiting nutrients was found to reduce yields at varying levels. Farmers' field validation of on-station results showed significant yield improvement compared to farmers' practice and the State recommendation.

Cowpea (*Vigna unguiculata* L.) is one of the important kharif pulses grown in India. It is a warm season crop, well adapted to many areas of the humid tropics and subtropical zones. Cowpea is tolerant to heat and dry conditions, but is intolerant to frost (Davis et al., 2000). The crop is grown from March to April and is harvested between June and July depending upon its end use. Incorporation of cowpea as a legume in crop sequences enriches soil fertility and provides a dense soil cover to check wind erosion and evapo-transpiration loss of soil water. It is grown throughout India for its long, green vegetable pods, seeds, and foliage for fodder.

In India, cowpea is grown on about 0.5 million ha with an average productivity of 600 to 750 kg grains/ha. Cowpea is highly responsive to fertiliser application and the dose of fertiliser depends on the initial soil fertility and moisture availability (Ahlawat and Shivakumar, 2005). Although cowpea is a legume, it still responds to a small application of starter N. Depending on soil status, application of P at 30 to 50 kg P_2O_5/ha was found optimum in several studies (Chauhan, 1972; Kumar and Singh, 1990). Response to applied K has not been uniform, but application of NPK at 25-50-25 kgN-P_2O_5-K_2O/ha was found optimum by Maharudrappa and Sharanappa (1990). This study was initiated to explore the possibility of improving productivity of cowpea through yield target-based fertiliser application in the Terai soils of North Bengal.

Table 1. Effect of nutrients on yield of cowpea.

Treatments	- - - - Grain yield, kg/ha - - - - First year	Second year	Mean	#Δ yield, kg/ha	% yield loss
T_1 (OPT)	1,102	1,123	1,113	-	-
T_2 (OPT-P)	807	965	886	227	20
T_3 (OPT-K)	944	954	949	164	15
T_4 (OPT-S)	944	988	966	147	13
T_5 (OPT-Zn)	670	890	780	333	30
T_6 (OPT-B)	1,118	1,179	1,149	-36	-3
T_7 (125% OPT)	1,108	1,705	1,407	-	-
T_8 (125% OPT-P)	817	855	836	571	40
T_9 (125% OPT-K)	919	978	949	458	32
T_{10} (125% OPT-S)	1,010	1,046	1,028	379	27
T_{11} (125% OPT-Zn)	1,042	1,025	1,034	373	26
T_{12} (125% OPT-B)	1,108	1,159	1,134	273	19
CD ($p = 0.05$)	390	530	-	-	

#Δ yield = Yield of OPT – yield of omitted nutrient treatment.

Table 2. Nutrient uptake expressed as kg/t of cowpea grain yield.

	N	P_2O_5	K_2O	S	Zn	B
Min	147	13	102	8	0.2	0.5
Max	195	28	157	27	0.7	1.1
Mean	169	18	125	14	0.4	0.8

The field experiment was conducted at the University farm at Pundibari, West Bengal, for two consecutive seasons. Soil fertility was determined from random soil samples (0 to 15 cm) from the experimental field following the Agro Services International (ASI) analytical methods (Portch and Hunter, 2002). Before the start of the experiment, a yield target-based recommendation for a target grain yield of 1 t/ha was developed for cowpea. The experiment was set up in a randomized complete block with 12 treatments and four replications. The treatments were based on the full soil test-based fertiliser recommendation of 30 kg N, 80 kg P_2O_5, 80 kg K_2O, 35 kg S, 8 kg Zn, and 1.5 kg B/ha, which was considered as the OPT. The first six treatments included the OPT and subsequent omission of P, K, S, Zn, and B from the OPT. Treatment T_7 amounted to 125% of the OPT where three major nutrients were applied at 25% higher than that of the OPT rate and the rates for S, Zn, and B where kept at the OPT level. Treatments T_8 to T_{12} were the corresponding omission treatments at the 125% OPT level. All the nutrients were applied basally. Uniform cultural practices and plant protection measures were used in all treatments. Harvesting was done at green pod stage to obtain the treatment-wise yields.

Abbreviations and notes: OPT = optimum; SR = State recommendation; STB = best soil test-based recommendation; FFP = farmers' fertilization practice; N = nitrogen; P = phosphorus; K = potassium; S = sulphur; Zn = zinc; B = boron; CD = Critical Difference, equivalent to Least Significant Difference.

Farmers' field trials in the third year compared the best soil-based treatment from the on-station trial with the state recommendation and farmers' fertilisation practice to assess the advantage of adopting soil test based fertilisation practices. Five farmers were selected from different villages under *Terai* conditions in the plains of Darjeeling district, all of Jalpaiguri district, and the upper region of CoochBehar district in West

Table 3. Farmers' field validation of on-station trial results (kg/ha).

Treatments	Farmer 1	Farmer 2	Farmer 3	Farmer 4	Farmer 5	Mean
State Recommendation (SR)	1,120	1,130	1,100	1,080	1,080	1,100
Best Treatment (STB)	1,520	1,530	1,540	1,550	1,530	1,530
Farmers' Practice (FP)	920	920	900	920	910	910
CD ($p = 0.05$)	130	2	22	12	8	
CV (%)	0.48	0.08	0.84	0.46	0.29	

Table 4. Economics of production of cowpea as influenced by different treatments in farmers' fields.

Treatments	Farmers	Cost of cultivation/ha, Rs.[1]	Yield, q/ha[2]	Total benefit[3]	Net benefit, Rs.
SR	F_1	14,742	11.16	17,856	3,113
	F_2	14,742	11.28	18,048	3,305
	F_3	14,742	11.04	17,664	2,921
	F_4	14,742	10.84	17,344	2,601
	F_5	14,742	10.81	17,296	2,553
STB	F_1	15,906	15.21	24,336	8,429
	F_2	15,906	15.34	24,544	8,637
	F_3	15,906	15.38	24,608	8,701
	F_4	15,906	15.49	24,784	8,877
	F_5	15,906	15.26	24,416	8,509
FFP	F_1	14,134	9.19	14,704	569
	F_2	14,134	9.18	14,688	553
	F_3	14,134	9.02	14,432	297
	F_4	14,134	9.18	14,688	553
	F_5	14,134	9.12	14,592	457

[1] Cost of cultivation = Fixed costs (See Table 5) + treatment-wise variable costs including: DAP (Rs.13/kg), KCl (Rs.7/kg), Sulfex or wettable S (Rs.65/kg), Zn-sulphate (Rs.40/kg), borax (Rs.40/kg).
[2] Multiply by 100 to get kg/ha
[3] Based on Rs.1,600 per quintal.

Bengal. The entire region is made up of alluvium laid down by the Himalayan Rivers such as the Teesta, Torsha, Jaldhaka, and other small rivulets. The Teesta has divided the area into two parts – the western part is known as the Terai and the eastern part as the Dooars. The plant and soil samples at harvest were analysed for nutrient concentration and uptake at maturity following standard procedures (Jackson, 1967).

The average two-season grain yield of cowpea (cv. Local) varied from 780 kg/ha to 1,407 kg/ha **(Table 1)**. Maximum yield of cowpea was obtained at 125% of the OPT nutrient application rate (T_7). Omission of nutrients from the OPT caused a yield loss that varied between 13 to 30%. Yield loss was highest with exclusion of Zn from the OPT followed by P, but K and S omission had a similar impact on yield. Yield loss was much higher with omission of nutrients from the 125% OPT treatment and yields were most affected with P omission (571 kg/ha) followed by comparable yield losses in the K, S, and Zn omission plots. Omission of B from the fertilisation schedule did not impact yield in the first year. Although this may be surprising considering the general deficiency of B in Terai soils, it was likely due to application of B in the previous crops in the sequence – which was probably enough to sustain yield of about 1,100 kg/ha. This scenario changed in the second year of experimentation as yield approached 1,700 kg/ha at 125% of the OPT rate **(Table 1)** where yield was seriously hampered due to omission of B. Johnston et al. (2009) recently argued that addition of high rates of N, P, and K can stimulate deficiency of a secondary or micronutrient that was indicated to be adequate according

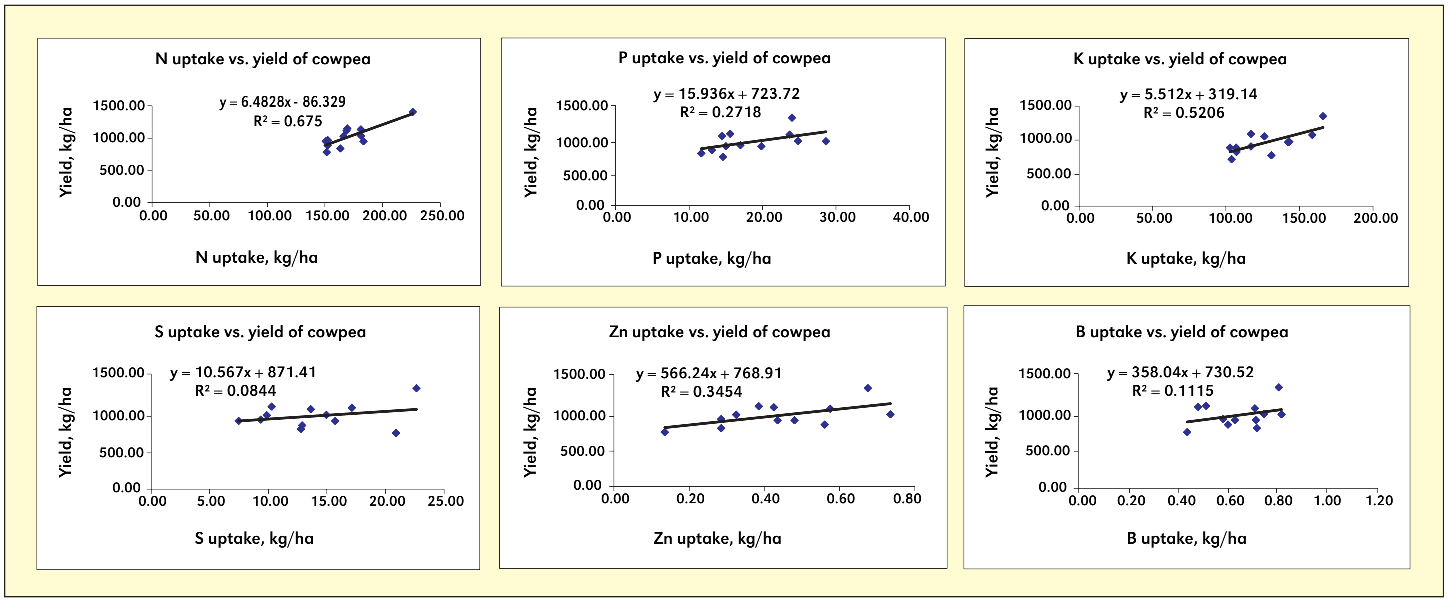

Figure 1. Interrelations between grain yield and uptake of nutrients in cowpea.

to soil testing. This experiment showed that the native B was sufficient to support a yield of about 1,100 kg/ha, but was inadequate to support 1,700 kg/ha. This suggests that the sufficiency/deficiency status of a particular soil nutrient is a dynamic parameter that varies with the yield target and this must be considered while formulating the fertilisation schedule for any crop.

The average uptake of nutrients by cowpea varied from 151 to 226 kg/ha for N, 12 to 28 kg/ha for P_2O_5, 103 to 159 kg/ha for K_2O, 8 to 23 kg/ha for S, 0.14 to 0.74 kg/ha for Zn, and 0.55 to 1.0 for B. The correlation between nutrient uptake and grain yield was poor in the first year (data not shown), but improved significantly in the second year **(Figure 1)** probably due to better utilisation of nutrients in the experimental plot that was kept fallow for 2 years before the start of the experiment. Significant correlation between yield and uptake of nutrients suggests that an appropriate range and mean uptake of nutrients per tonne of grain yield are provided in **Table 2**.

The best treatment obtained in the on-station trial was validated and compared against the current SR and FP in farm fields. Results showed that the average grain yield in the farmers' fields varied from 910 to 1,530 kg/ha depending on the treatment. The yield advantage of the best treatment was about 400 kg/ha over the SR and about 600 kg/ha over FP **(Table 3)**. Economics of production, calculated on the basis of fixed cost and treatment-wise variable cost **(Tables 4 and 5)**, revealed that the yield advantage in the best treatment translated to average extra benefit of Rs.5,000 over the SR and Rs.8,000 over the existing FFP.

Soil testing and yield target-based fertiliser recommendations significantly improved the yield of cowpea under the Terai alluvial situation of West Bengal. Along with P and K, S, Zn, and B significantly influenced yield. Further research is required to refine nutrient application rates to ensure profitability is being maximised with the nutrient treatments. Both on-station and on-farm trials suggested the need for integration of micronutrient and secondary nutrient application with macronutrients to achieve high yield of cowpea.

Table 5. Outline of fixed costs for cowpea production.

Fixed cost Items	Rate, Rs.	Total, Rs.
Land preparation		
a. Tractor ploughing	160/hr	640
b. Laddering by bullock	75/ploughing	150
Fertilizer application, sowing, and layout preparation	75/man unit	1,126
Seed materials	250/kg	5,000
Irrigation	200/irrigation	200
Plant protection measure	100	100
Harvesting and threshing	75/man unit	751
	Total	7,967

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Research Supported by IPNI India Programme

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.

North & East India and Bangladesh

Project Number	Title
BANGLADESH-05	Maximising Crop Production through Nutrient Management
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 Soils of 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
NWZ INDIA-59	Balanced Fertilisation for Quality Fruit (Mango) Production in Uttar Pradesh
NWZ INDIA-63	Site-Specific Nutrient Management for Maximum Economic Yield of Wheat and Potato in Partially Reclaimed Sodic Soil of Arid Zone of Agra
NWZ INDIA-69	Assessment of Phosphorus and Potassium Requirements for Maximum Economic Yield of Major Crops of Central Plain Zone of Uttar Pradesh
NWZ INDIA-72	Appraisal of Multi-Nutrient Deficiencies and their Redressal through Site-Specific Nutrient Management
NWZ INDIA-73	Evaluating Production Systems Approaching Attainable Yields and Profits

South India and Sri Lanka

Project Number	Title
SZ INDIA-47	Investigations on Balanced Fertilisation for Breaking Maize Yield Barriers in Tamil Nadu
SZ INDIA-49	Site-Specific Nutrient Management (SSNM) for Maximisation of Crop Productivity in Southern Karnataka
S INDIA-50	Site-Specific Nutrient Management (SSNM) for Maximum Economic Yield and Quality of Transgenic Cotton in Northern Karnataka
S INDIA-51	Site-Specific Nutrient Management in Maize-Wheat Cropping System in Northern Karnataka

West India

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 in Maharashtra
W INDIA-1	Inventory of Available Potassium Status and Modeling Its Relationships with Potassium Content, Yield, and Quality of Sugarcane for Site-Specific Nutrient Management in Sugarcane-growing Soils of Maharashtra

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

RESPONSIBLE USE OF FERTILISER NUTRIENTS — A BALANCING ACT CONTINUES

Greetings and welcome to the third issue of BETTER CROPS-INDIA. We are happy to provide you with this annual publication from the International Plant Nutrition Institute (IPNI), featuring articles on research projects related to fertiliser use in India. We welcome your comments on this publication, and suggestions for future issues.

It is ironic that at the close of 2009 we have seen one of the most erratic years in the global fertiliser industry. After demand for fertiliser nutrients soared, along with prices, they have both declined once again. The impact of the global economic crisis seems to have completely shadowed the issue of a food crisis, something we were focused on last year at this time. However, the reality is that the world continues to have only very limited food reserves, a fact which has not changed with all of the concern about international credit and finance. We are no further ahead than we were at the end of 2008; in fact, we are more than ever facing potential food shortage problems in many parts of the world once again in the near future.

The issue of making fertiliser recommendations based on site-specific conditions has formed the basis of the IPNI Programme in India. For the most part, we have clearly demonstrated that field-specific soil testing, which evaluates the sample for all macronutrients, secondary nutrients, and micronutrients, provides the necessary information to overcome the nutrient deficiencies limiting full yield response. These results, when added to the overwhelming number gathered by other Indian researchers, clearly demonstrate that the "yield stagnation" so often referred to in Indian food production has some clear solutions. However, we continue to see little to no response in the way of expanding soil testing services or offering a wider set of soil analysis services in the country – a major challenge. We have initiated work in India with international research partners to address this issue in the development of nutrient management decision support systems. While these tools may not fully replace soil testing, they will add significant support to making improved fertiliser recommendations in a country like India. We are optimistic that the future of food production in India will show the increases necessary to keep pace with the growing population.

Fertilisers are an important player in the production of food and protein in society, and especially Asian society. Ranging between 40 to 60% – that is the estimated amount of the global food supply which is attributed to fertiliser use. We understand the impact of fertiliser use on food security, as well as the need to foster the responsible use of fertiliser nutrients based on farmer economics and environmental impact. It is this balancing act which guides our efforts as we move forward into the future.

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BETTER CROPS–INDIA

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