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 multi-nutrient 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. BC INDIA

Drs. B.S. Dwivedi, Dhyan Singh, A. Swarup, M.C. Meena and Mr. R.L. Yadav are with Division of Soil Science and Agricultural Chemistry, Indian Agricultural Research Institute, New Delhi; Drs. K.N. Tiwari and K. Majumdar are with IPNI-India Programme; and Dr. K.S. Yadav is with Krishi Vigyan Kendra, Shikohpur, Gurgaon.

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