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Use of Balanced Fertilization for Achieving Higher Productivity of Pearl millet and Soil Health under Pearl millet Based Cropping Systems

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Abstract: In India, pearl millet grown in 7.41 mha area with an average production of 10.3 mt. Analysis of 1030 soil samples from major pearl millet growing areas representing 10 districts indicated widespread multi-nutrient deficiency involving two to six nutrients *viz.* N & K; N, K & S; N, K & B; N, P, K & S; N, K, S & Zn and N, P, K, S, Zn & B. Incidence and expansion of such multi-nutrient deficiencies in soils is due to inadequate and unbalanced nutrient input through fertilizers and is considered as one of the major constraints in enhancing productivity of pearl millet. In this context, different nutrient supply options were evaluated in pearl millet - based cropping systems. In all these experiments, site-specific nutrient management proved superior to state recommendation and farmers' fertilizer practice in terms of annual pearl millet yields, nutrient recovery, soil fertility restoration and net economic returns. Site-specific nutrient management seems to be one of effective ways to improve nutrient supplying capacity of soil and enhance the productivity of pearl millet in India.

Key words: Pearl millet, SSNM, soil health, multi-nutrient deficiencies, productivity, economics.

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Constant decline in soil fertility status is considered one of the serious second-generation problems of Post-Green Revolution era. Depletion of soil fertility in terms of ever-widening deficiencies of macro- and micro-nutrients is not only responsible for stagnation or slowing down the production and productivity of major food grain crops, but it has also threatened nutritional and economic security. Unbalanced fertilizer uses prevalent even in agriculturally advanced areas is the prime cause for such undesirable trends in soil fertility (Meena *et al.*, 2017). It is unfortunate that the fertilizer recommendations included in the package of practices of different states and those formulated for individual fields by the soil testing laboratories are of *ad-hoc* nature, and hardly consider yield targets and nutrient removal by the crops. Also, the recommendations are confined to NPK in majority of cases, whereas the fact remains that in the current age of multi-nutrient deficiencies the face of balanced nutrition has been completely changed.

In order to develop judicious site-specific nutrient input schedules, as also to ensure timely input availability of fertilizers at the farmers' doorstep, a thorough knowledge of the changing scenario of soil fertility under diverse agro-ecologies is a pre-requisite. In fact, multi-nutrient deficiency is more talked about at different platforms than actually understood in correct perspective. Information on the extent and nature of multi-nutrient deficiencies in pearl millet growing area is completely lacking, though the same is of vital significance to rationalize fertilizer use (Dwivedi *et al*., 2011). Equally important is to redefine soil fertility evaluation criteria. The low, medium and high fertility classes suggested in 1950s need to be revised in the light of frequently documented crop responses to fertilizers in the soils of 'medium' or 'high' fertility categories.

Since the nature of multi-nutrient deficiencies varies in accordance with soil, climate and management factors, any *ad-hoc* fertilizer recommendations would be of limited significance. Routine NPK recommendations prescribed by soil testing labs may rather hasten the pace of mining of nutrients that are not included in fertilizer schedule but are apparently or potentially deficient. Unless balanced fertilization connotes soil-test based site-specific nutrient management (SSNM), it is no longer 'balanced'. Unfortunately actual field-based information on SSNM is scarce. Studies taken-up so far were mostly confined to fertilizer N scheduling [real-time N application using leaf color chart (LCC) or chlorophyll meter] in researcher managed on-station experiments. SSNM involving all deficient nutrients was seldom attempted on cultivators' fields. There is, however, an urgent need to generate SSNM recommendations in order to achieve sustained higher productivity and farm profit under pearl millet-based cropping systems. A farmer-participatory mode would be preferable in order to enhance awareness among the farmers, ensure larger scale adoption of recommendations and also to receive feedback for any further refinement.

Pearl millet was grown in 7.41 mha area with production of 10.3 mt during 2020-21. The major pearl millet growing states are Rajasthan, Maharashtra, Gujarat, Uttar Pradesh and Haryana which account for more than 90% of pearl millet acreage in the country and commonly grown in rainy (*kharif*) season. More than 51% of total pearl millet growing area of India is located in Rajasthan (http://agropedia.iitk.ac.in/content/area-and-distribution-pearl-millet).

In order to advise a systematic approach on the basis of previous work done to assess the nature and extent of multi-nutrient inadequacies in the soils of pearl millet growing areas and the role of site-specific balanced fertilizer use in augmenting pearl millet productivity, grain quality, farm profit and soil health under pearl millet-based cropping systems.

Material and Methods

Assessment of multi-nutrient deficiencies in pearl millet growing areas

Soil samples (1031 numbers; 0-15 cm depth) were collected from major pearl millet growing agro-ecological sub-regions (AESRs) represented by 10 districts *i.e*. Jodhpur, Kota, Gurgaon, Hisar, Banaskantha, Mehsana, Agra, Kanpur City, Faizabad and Varanasi (Table 1). One village each in the selected district of AESRs representing predominant soil type and pearl millet-based cropping systems of the AESR was chosen for sampling. About 100 soil samples were drawn, following standard sampling procedures, from each representative village. Information on the history of sampled fields such as crops grown, amount and type of fertilizers and manures used, productivity level *etc*. were recorded at the time of soil sampling.

Soil analysis and fertility evaluation

Soil samples were processed and analyzed for different soil fertility parameters as per standard procedures (Table 2).

For soil fertility evaluation, two categories *viz*. 'fertilizer responsive' and 'fertilizer non-responsive' were used in place of the conventional 'low', 'medium' and 'high' fertility ratings. The 'fertilizer responsive' category included 'low' and 'medium' fertility soils, whereas the soils belonging to 'high' fertility were rated as 'fertilizer non-responsive'. This modified soil fertility evaluation criterion was adopted in the light of a large number of the research reports indicating frequent

Table 1. Details of soil samples collected from important pearl millet growing agro-ecological sub-regions (AESRs)

Ecosystem/AESR No. and Name	State	Village, District	No. of samples
Arid ecosystem			
2.1 Marusthali	Rajasthan	Birawas, Jodhpur	100
2.3 Rajasthan Bagar and North Gujarat Plain	Haryana	Pattan, Hisar	100
	Gujarat	Deesa, Banaskantha	100
Semi-arid ecosystem			
4.1 North Pb. Plain and Ganga-Yamuna Doab	Uttar Pradesh	Agra	125
	Haryana	Gurgaon	100
4.2 North Gujarat Plain	Gujarat	Mehsana	100
4.3 Ganga-Yamuna Doab Plain	Uttar Pradesh	Champatpur, Kanpur City	100
5.2 Madhya Bharat Plateau	Rajasthan	Bhakadkheri, Kota	100
Sub-Humid ecosystem			
9.2 Rohilkhand, Awadh and South Bihar Plain	Uttar Pradesh	Malikpur, Faizabad	106
		Tohfapur, Varanasi	100
Total			1031

and significant crop responses to fertilizers in 'medium' fertility soils, and thus emphasizing a need for merger of 'low' and 'medium' categories. With these fertility ratings, soils containing organic C ≥ 0.75%, available P ≥ 25 kg ha^{-1}, available K ≥ 280 kg ha^{-1} or available S ≥ 22.5 kg ha^{-1} were placed in N, P, K or S non-reponsive category, respectively. The threshold levels for 1*N* NH_4OAc-extractable Ca and Mg were 1.5 and 1.0 cmol kg^{-1} of soil, respectively. Similarly, the threshold levels for DTPA- extractable Zn, Fe, Cu and Mn were 0.8, 4.5, 0.2 and 2.0 mg kg^{-1}, respectively, which differentiated responsive soils from the non-responsive ones. Soils containing ≤ 0.5 mg kg^{-1} of hot water soluble B was rated responsive to B application.

Soil fertility appraisal and multi-nutrient deficiencies

Soil samples from important pearl millet growing districts were analyzed for soil pH, EC, organic C, available N, P, K, S, Zn, Fe, Cu, Mn and B. Soil samples were classified in two categories *viz*. 'fertilizer responsive' and 'fertilizer less responsive'. This approach of rating was used in place of the conventional one, *i.e.* 'low', 'medium' and 'high'. The 'fertilizer responsive' category included 'low' and 'medium' fertility soils, whereas the soils belonging to 'high' fertility were rated as fertilizer less-responsive. Results indicated widespread deficiencies of eight nutrients, namely N, P, K, S, Zn, Fe, B and Ca in the soils of important pearl millet growing agro-ecological sub-regions (AESRs). The prominent multi-nutrient deficiency combinations in soils of important pearl millet growing districts revealed that available status of a particular nutrient varied from place to place. Deficiency of maximum 6 nutrients was recorded in Gurgaon whereas in other locations, deficiency of 2 to 5 nutrients was observed. Most common multi-nutrient deficiency was related to 3 major primary nutrients *i.e.* N, P and K. Problem of deficiency of these nutrients further aggravated due to conjoint deficiency of secondary

Table 2. Standard procedures followed for soil analysis

Parameters	Analytical procedures	References
pH and Electrical Conductivity	Soil:water (1:2) suspension	Page *et al*. 1982
Organic carbon	Chromic acid titration	Walkley & Black 1934
Available P	0.5 *M* $NaHCO_3$ (pH 8.5) 0.03 *N* NH_4F+0.025 *N* HCl	Olsen *et al*. 1954 Bray & Kurtz 1945
Available K	1 *N* NH_4OAc (pH 7.0)	Hanway & Heidel 1952
Available S	0.15 % $CaCl_2$	Williams & Steinbergs 1969
Available Zn, Fe, Cu, Mn	DTPA-TEA-$CaCl_2$ (pH 7.3)	Lindsay & Norvell 1978
Available B	Hot water	Gupta 1967

Table 3. Nature and extent of multi-nutrient deficiencies in soils of important pearl millet growing districts

AESR No.	District	Village/Tehsil	Multi-nutrient deficiencies
2.1	Jodhpur	Birawas	NPKZn(13), NPKSZn(12), NPKZnFe(9)
2.3	Hisar	Pattan	NPK(26), NPKFe (16), NP(14), NPFe(13)
2.3	Banaskantha	Deesa	NK(36), NPK(10), NPKFe(8)
4.1	Gurgaon	Lohtaki	NKS(16), NS(12), NSB(11), NPKSZnB(7)
4.1	Agra	Sahara	NZn(24), NP (6), NPZn (4), NKZn(4) and NPSZn (4)
4.2	Mehsana	Mehsana	NK(31), NPK(24), NPKSFe(6)
4.3	Kanpur City	Champatpur	NKS(33), NPKS(21), NK(10)
5.2	Kota	Bhakadkheri	NP(14), NPK(7), NK(5)
9.2	Faizabad	Malikpur	NPKZn(38), NKZn(22), NK(18), NPK(18)
9.2	Varanasi	Tohfapur	NPKZn(28), NPKSZn(21), NP(11), NKZn(9), NKSZn(9)

and micronutrients particularly S and Zn. Occurrence of such multi-nutrient deficiency may be ascribed to soil properties, management practices, prevailing cropping systems and climate conditions. Such contention can derived support from earlier findings of researchers (Yadav and Meena, 2009; Dwivedi *et al.,* 2011; Meena *et al.*, 2017; Kumar *et al*., 2020).

Redressal multi-nutrient deficiencies through SSNM in pearl millet-based systems

Village Lohtaki in Gurgaon district of Haryana (AESR 4.1) was chosen for on-farm experimentation, with broad objective of understanding the kind of SSNM package needed to address prevalent multi-nutrient deficiencies in the soils of the village, and educating the farmers about the significance of SSNM in terms of high yields and economic returns. The final selection of the village was preceded by a diagnostic survey of 06 villages to understand the cropping systems and farmers' crop management practices. Village Lohtaki represented semi-arid climate of Upper Gangetic Plain transect of the Indo-Gangetic Plains region (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.

Technical program: Twenty-eight on-farm experiments *i.e.* eight with pearl millet-wheat and six with pearl millet-mustard cropping system during 2007-08 and similar number of experiments during 2008-09, were conducted in village Lohtaki (28°16′43.5″N, 77°06′09.4″E) Gurgaon Haryana. For each experiment, half-acre (2000 m^2) farm area was divided into seven strips to impose seven fertilizer treatments *i.e.* T_1: SSNM; T_2: Fertilizer 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 fertilizer practice (FFP) + K; and T_7: FFP. Fertilizer rates in SSNM and TY varied for different experiments in accordance with soil test values. Averaged across the experimental sites, fertilizer N, P_2O_5, K_2O rates for SSNM were 150, 62, 105 kg ha^{-1} in pearl millet, 150, 58, 75 kg ha^{-1} in wheat and 120, 60, 100 kg ha^{-1} in mustard respectively, and the corresponding rates for TY in these crops were 120, 30, 62 in pearl millet 192, 34, 77 in wheat and 122, 69, 114 kg ha^{-1} in mustard, respectively. On the other hand, fertilizer 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^{-1} alone in pearl millet, 80 kg N with 57.5 kg P_2O_5 ha^{-1} in wheat and 60 kg N with 60 kg P_2O_5 ha^{-1} in mustard. The SRs for these crops were 125 kg N, 62.5 kg P_2O_5, and 10 kg $ZnSO_4$ ha^{-1} in pearl millet; 150 kg N, 60 kg P_2O_5 and 30 kg K_2O ha^{-1} in wheat and 80 kg N, 30 P_2O_5 and 250 kg gypsum ha^{-1}, in mustard.

Hybrid pearl millet cv. 'JKDH 676', wheat cv. 'WH 711' and mustard cv. 'Pusa Bold' were grown in the on-farm experiments. In all crops one-third of total N, half of total K and entire quantity of P, S, Zn and B as per treatment was applied as basal dressing at the time of sowing. Remaining amount of N and K was top-dressed in two and one splits, respectively.

Table 4. Grain yield of pearl millet under pearl millet-based cropping systems as influenced by different fertilizer options

Treatment	*Pearl millet* - wheat System (18 experiments averaged)		*Pearl millet* - mustard System (12 experiments averaged)	
	Pearl millet	Response over FFP	*Pearl millet*	Response over FFP
SSNM	4.02	1.81	4.11	1.66
TY	3.52	1.31	3.48	1.03
TY+Micro	3.91	1.70	3.88	1.43
SR	3.04	0.83	3.00	0.55
SR+K	3.58	1.37	3.62	1.17
FFP+K	2.62	0.41	2.70	0.25
FFP	2.21	-	2.45	-
LSD ($p<0.05$)	0.29	-	0.22	-

In pearl millet-wheat system, S, Zn and B were applied to pearl millet only and wheat drew residual benefit of these nutrients. In the other cropping system, however, mustard also received S in SSNM, TY+Micro, SR and SR+K treatments. All the experiments were conducted in farmer-participatory mode, and were managed by the farmers themselves under technical guidance of the researchers. Management practices, except fertilizer rate, were kept uniform across the treatments. The crops were harvested manually at maturity, and the harvested aboveground biomass was removed from the plots. The harvested biomass was sun-dried and yields recorded at constant moisture content.

Initial and post-harvest soil samples (0-15 cm depth) were collected from all plots, and analysed for available nutrient content following Page *et al.* (1982). For comparison of monetary returns under different fertilizer management options, the cost (per kg) of fertilizer N, P_2O_5, K_2O, S, Zn and B was taken as Indian Rupees (Rs.) 10.50, 16.22, 7.43, 10.00, 35.00 and 25.00, respectively. The price (per tonne) of pearl millet, wheat and mustard grain was Rs. 6100, 10400 and 18600 and that of straw/stover was Rs. 1000, 2000 and 400, respectively. For the statistical analysis of the yield data, individual experiments were treated as replicates, and the data of the on-farm experiments was analysed as per ANOVA of randomized block design.

Diagnostic surveys: Detailed interactions with the farmers of village Sirska, Khaika, Daula, Abhaypur, Lakhuvas and Lohtaki (all in Gurgaon district) were held to understand the cropping systems of the area, management practices particularly fertilizer use, and crop productivity levels. The surveys revealed that pearl millet was the predominant crop grown in monsoon season, whereas mustard and wheat were the major winter season crops. Thus, the two distinct cropping systems followed in the area were pearl millet-mustard and pearl millet-wheat. Farmers grew high yielding cultivars of these crops with very low and unbalanced fertilizer application. For instance, hybrid pearl millet with an achievable yield potential of 4.0 t ha^{-1} received, on the name of fertilizer, 60 kg N ha^{-1} only. Winter crops are grown with NP fertilizers, but the use of K, S and micronutrients was largely ignored. As a result, average crop productivity of not only Lohtaki - the village chosen for field experiments, but that of the neighboring villages adopting similar cropping system and fertilizer use practices was extremely low. The average productivity of pearl millet, mustard and wheat in the surveyed villages was 1.5-2.0 t ha^{-1}, 1.0-1.6 t ha^{-1} and 3.0 t ha^{-1}, respectively.

Initial soil fertility status of on-farm experimental sites: The initial soils of the experimental sites in Lohtaki village were mildly alkaline (pH 7.40 to 8.08) and non-saline (EC 0.06 to 0.10 dS m^{-1}). 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 26 out of 28 sites containing available K in the range of 43-185 kg ha^{-1} were categorized as responsive to K fertilizer. Eighteen sites were deficient in P, 16 each in S and Zn, and 06 sites had low (<0.5 mg kg^{-1}) B content.

Results and Discussion

Yield response to fertilizer options in pearl millet under pearl millet-wheat system: Pearl millet grain yield, averaged across the 16 on-

Plate 1. Pearl millet performance under SSNM.

farm experiments, varied from 2.21 t ha^{-1} under farmer's fertilizer practice (FFP) to as high as 4.02 t ha^{-1} under SSNM (Table 4, Plate 1). The effect of SSNM was more apparent on ear head length (26.1 cm) and girth (3.15 cm), which were distinctly greater than in FFP (22.2 and 2.6 cm, respectively). The SSNM treatment wherein nutrients were applied not only to meet the crop demands but also to avoid any mining from soil reserve, out-yielded the targeted yield (TY) treatment that received NPK as per AICRP-STCR's yield adjustment equations. The mean yield difference of 0.50 t ha^{-1} between these two treatments was partly ascribed to inclusion of secondary and micronutrients (S, Zn and B) in SSNM. The extremely low available K content of the experimental soils was very much reflected in crop performance and also in yield response to fertilizer K. Inclusion of 45 kg K_2O ha^{-1} alone in FFP produced an additional grain yield of 0.41 t ha^{-1}. The benefit of K fertilization was, however, greater (0.54 t ha^{-1}) when SR was supplemented with fertilizer K. Surprisingly, the SR for a K-exhaustive crop like pearl millet 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. More or less similar responses of crops to applied nutrients were earlier reported by Meena *et al.* (2017).

On the whole, balanced and site-specific fertilizer use under SSNM, TY or TY + Micro proved distinctly superior to the SR (Fig. 1), suggesting thereby the need for revision of state recommendations. Surprisingly, the state recommendations for a K-exhaustive crop like pearl millet were devoid of K, causing not only a substantial yield loss year after year but also an excessive mining of already depleted native K reserves.

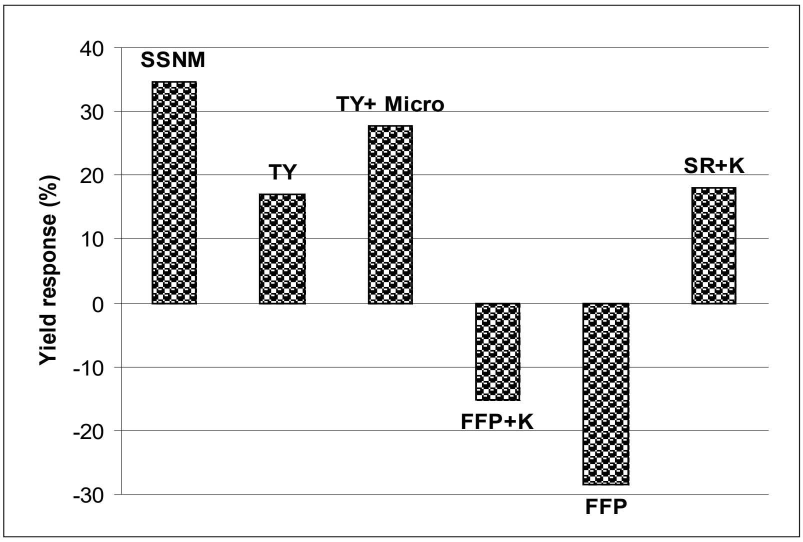
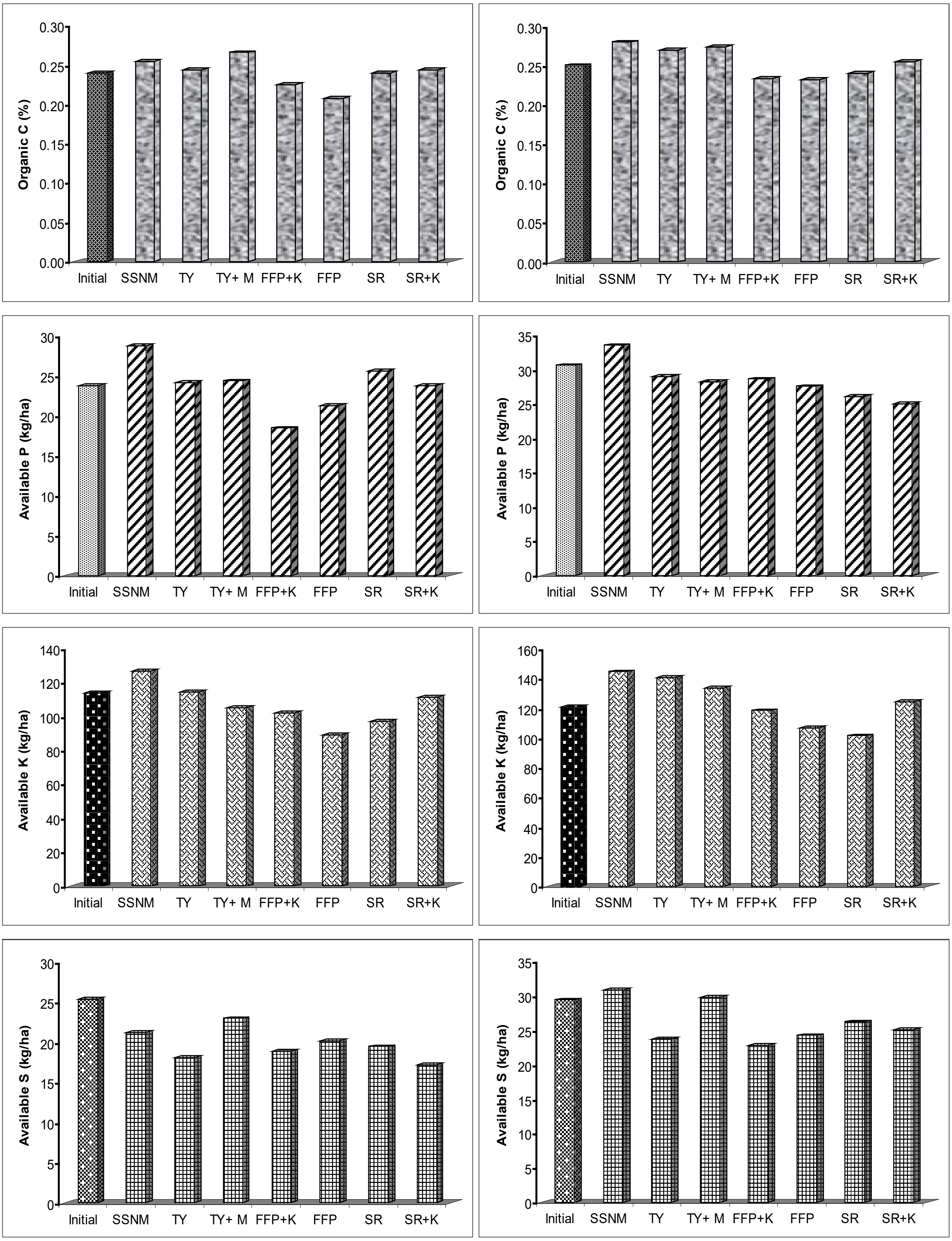


Fig. 1. Grain yield response of pearl millet under different nutrient management options over state recommendation (SR) in pearl millet-wheat system



(a) Pearl millet-wheat system *(b) Pearl millet-mustard system*

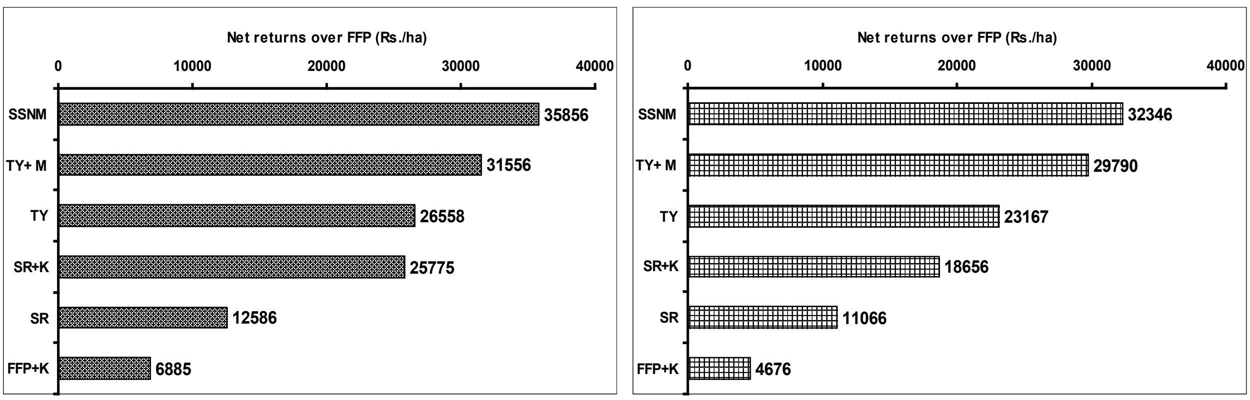
Fig. 2. Soil fertility status (0-15 cm depth) in on-farm experiments at Lohtaki (Gurgaon) under (a) pearl millet-wheat, and (b) pearl millet-mustard cropping systems

Yield response to fertilizer options in pearl millet-mustard system: The treatment effects in pearl millet were similar to those noticed in pearl millet-wheat system, although the grain yield, averaged across 12 experiments, ranged between 2.45 and 4.11 t ha^{-1}, with the lowest in FFP and the highest in SSNM (Table 4).

Inclusion of S and micronutrients (Zn and B) in TY brought a yield increase of 0.40 t ha^{-1}. The SR + K, *i.e.* SR supplemented with fertilizer K_2O at 1.5 times of the P_2O_5 rate, produced, an additional yield of 0.62 t ha^{-1} over SR. Yield responses over FFP were the highest in SSNM (68%), followed by TY + Micro (58%), SR + K (48%) and TY (42%) (Dwivedi *et al.*, 2011).

Effect on soil fertility status: Analysis of soil samples (0-15 cm) collected after completion of the pearl millet-wheat or pearl millet-mustard cropping cycles revealed only a marginal improvement in organic C content under SSNM and TY treatments over the initial content (Fig. 2). Treatment effects, on the other hand, were more spectacular with respect to available P or K content. On average soil available P under SSNM was greater than the initial content by 3 kg ha^{-1} in post-mustard and by 5 kg ha^{-1} in post-wheat samples, whereas a depletion of about 5 kg P ha^{-1} under SR + K in post-mustard and that of 5.3 kg ha^{-1} under FFP + K in post-wheat samples was recorded. In post-mustard analysis available K content registered an average increase (over the initial value) of about 24, 20 and 13 kg ha^{-1} in SSNM, TY and TY + Micro treatments, respectively (Fig. 2). The K content, however, got depleted in FFP and SR treatments, and the magnitude of such depletion was 13-18 kg ha^{-1}. The corresponding figures for K depletion were relatively greater (17-25 kg ha^{-1}) in post-wheat samples. The build-up (under SSNM only) was also of relatively smaller magnitude (12 kg ha^{-1}). These treatment effects could be explained in the light of differential K requirement of the two cropping systems. Available S content of post-mustard soil was fairly maintained at the initial level in SSNM and TY+Micro treatments, whereas an average decline of 3.2 to 6.7 kg ha^{-1} compared with the initial content was recorded in other treatments. A general decline of varying magnitude (2.4 to 8.2 kg ha^{-1}) in available S content was, however, recorded in post-wheat soils. Relatively higher soil S content in post-mustard soils is ascribed mainly to the sub-surface feeding nature of tap-rooted mustard crop and partly to the direct S application in 04 treatments *i.e.* SSNM, TY+Micro, SR and SR+K.

Economics of SSNM vis-à-vis other fertilizer practices: Based on the yield response data (Table 4), economics of different fertilizer options over FFP was worked out (Fig. 3). In pearl millet-wheat cropping system, net returns, was higher (Rs. 35856 ha^{-1}) under SSNM, followed by TY+Micro (Rs. 31556 ha^{-1}) and TY (Rs. 26558 ha^{-1}). Supplementing K to the state recommendations (SR) almost doubled the net-returns over the SR (Rs. 12586 ha^{-1}) (Majumdar *et al.*, 2012; Meena *et al.*, 2012). In pearl millet-mustard system also, the profits increased substantially consequent to adoption of improved fertilizer practices. Net returns under different fertilizer options followed a trend similar to pearl millet-wheat system with highest values (Rs. 32346 ha^{-1}) under SSNM. Inclusion of K in state recommendation (SR)



(a) Pearl millet-wheat cropping system *(b) Pearl millet-mustard cropping system*

Fig. 3. Net economic returns under different fertilizer options vis-à-vis FFP in the on-farm experiments at village Lohtaki (Gurgaon)

brought, on average, additional net return of Rs. 7500 ha^{-1}.

Results of these on-farm experiments thus clearly established the significance of SSNM and other improved fertilizer practices, such as AICRP-STCR recommendations supplemented with secondary and micronutrients, in improving crops yield and economic returns on one hand, and restoration soil fertility on the other.

Conclusion

On-farm experiments conducted with pearl millet-wheat and pearl millet-mustard cropping systems established superiority of soil test-based site-specific nutrient management (SSNM) over other fertilizer options in augmenting the pearl millet yield and economic returns. The results revealed that the productivity of pearl millet could be almost doubled with the adoption of soil test-based SSNM that includes application of all deficient nutrients. Deficiency of 2 to 5 nutrients was observed in soils of pearl millet growing area. Most common multi-nutrient deficiency was related to N, P, K, S, Zn, Fe and B. There is immediate action needed to address these multi-nutrient deficiencies through SSNM for sustainable agriculture. The SSNM or other improved fertilizer options like AICRP-STCR prescriptions along with S and deficient micronutrients either prevented nutrient depletion from soil or improved soil fertility status despite enhanced removal by the crops under these treatments. Substantial yield responses (direct as well as residual) to K and secondary and micronutrients (S, Zn and B) suggested that balanced fertilizer use no longer meant application of NP or NPK, but it should necessarily include all nutrients that are deficient at a particular site.

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