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Site-specific nutrient management is a key for enhancing productivity of rapeseed-mustard in India

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Abstract

In India, rapeseed-mustard alone contributes in total oil production to the extent of about 24% with its average productivity of about 1.00 t ha^{-1}. Analysis of 1601 soil samples from major mustard growing areas representing 14 agro-ecological sub-regions (AESRs) indicated widespread multi-nutrient deficiency involving 2 to 6 nutrients including NK, NKS, NKB, NPKS, NKSZn and NPKSZnB. Incidence and expansion of such multi-nutrient deficiencies in Indian soils owing to inadequate and unbalanced nutrient input through fertilizers is considered one of the major constraints in enhancing productivity of oilseed crops. In this context, different nutrient supply options namely T_1: SSNM; T_2: State *ad-hoc* recommendation plus potassium (SR) + K; T_3: SR; T_4: Farmer's fertilizer practice (FFP) + K; and T_5: FFP were evaluated in Lohtaki village district Gurgaon representing AESR 4.1 with pearlmilet-mustard cropping system. On an average, mustard grain yield responses over FFP across the experiments were the highest in SSNM (85%), followed by SR+K (40%) and SR (24%). Average net return over FFP in pearlmillet-mustard cropping system was higher (Rs. 43963 ha^{-1}) under SSNM, followed by SR+K (Rs. 26092 ha^{-1}) and SR (Rs. 15693 ha^{-1}). In all these experiments, SSNM proved superior to state recommendation and farmers' fertilizer practice in terms of annual crop yields, nutrient recovery, soil fertility restoration and net economic returns. Site-specific nutrient management (SSNM) seems to be one of effective ways to improve nutrient supplying capacity of soil and enhance the productivity of mustard, which in turn will help in achieving much needed self sufficiency in oilseeds production in India.

Key words: *Economics, Indian mustard, multi-nutrient deficiencies, productivity, soil health, SSNM*

Introduction

Major oilseed crops in India include rapeseed-mustard, groundnut and soybean, which contribute approximately 80% oil production. India is the second largest importer of edible oilseeds after China. A substantial amount of edible oil is imported in our country (Meena *et al*., 2015). Country spends huge amount annually to augment domestic supplies. Therefore, there is an urgent need of enhancing the productivity of oilseed crops. Among oilseed crops, rapeseed- mustard alone contributes to the extent of about 24% of total oil production of the country with an average productivity about 1.00 t ha^{-1}. Area under the cultivation of this crop about 6.34 million hectare (Mha) (Fig. 1) (MoA&FW, 2015). There are reports to indicate that productivity of mustard is more than 2 t ha^{-1} in well managed field (Meena *et al*., 2006b; Mehta *et al*., 2013). This gap can be minimized through proper management of soil health specifically soil fertility (Meena *et al*., 2016). In this context, site-specific nutrient management (SSNM) can be an effective tool to enhance the productivity of oilseed crops in general and mustard in particular (Dwivedi *et al*., 2009).

Constant decline in soil fertility status is considered as one of the serious second-generation problems of post-Green Revolution era (Dwivedi and Meena, 2015). Recent report based on 1,27,752 GPS-

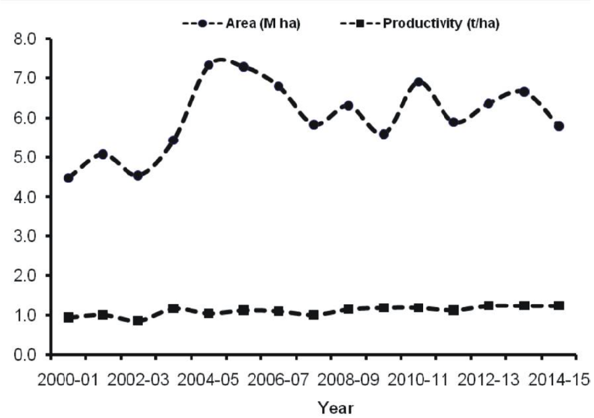


Fig. 1: Area and productivity of mustard in India during 2000-01 to 2014-15

coordinated soil samples on micronutrient delineation in Indian soils has shown that more than 43% soils are deficient in Zn, 14.4% in Fe, 6.1% in Cu, 7.9% in Mn and 20.6% deficient in B (Shukla *et al*., 2016a; Shukla *et al*., 2016b). Depletion of soil fertility in terms of ever-widening deficiencies of macro- and micronutrients is not only responsible for stagnation or slowing down the production, productivity and growth rates of major oilseeds crops (Meena *et al*., 2006a), but also adversely affect the human health due to deficiency of minerals. Diagnostic surveys indicate that in several high productivity areas of irrigated ecosystems, farmers often resort to excessive use of fertilizer N to maintain the yields at levels attained previously with relatively lower fertilizer rates (Dwivedi *et al*., 2012; Dwivedi *et al*., 2016). Such indiscriminate use of N fertilizers not only aggravates the extent of soil fertility depletion with respect to nutrients other than N but also proves ultimately harmful in terms of low nutrient use efficiency, poor quality of produce, enhanced susceptibility of crops to biotic and abiotic stresses (Meena *et al*., 2015), and a potential threat of groundwater pollution due to excessive leaching of nitrates beyond effective root zone (Dwivedi *et al*., 2012). In the present era of multi-nutrient deficiencies, balanced fertilization no longer means pre-fixed NP or NPK application (Singh *et al*., 2012). The fertilization schedules should invariably include all deficient secondary and micronutrients. For development of such pragmatic fertilizer prescriptions, however, a thorough understanding of the nature and extent of nutrient deficiencies in the soils of different agro-ecologies is a pre-requisite. Equally important is to redefine the soil fertility evaluation criteria in the light of changing crop response scenario where economic yield responses due to nutrient input are frequently reported on the soils that are conventionally classified as 'medium' or 'high' fertility soils (Majumdar *et al*., 2012; Das *et al*., 2015).

Unless balanced fertilization connotes soil-test based 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 LCC or chlorophyll meter) in researcher managed on-station experiments (Dwivedi *et al*., 2016). 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 in the adverse climate. 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. With this backdrop, a systematic study was initiated on assessment of multi-nutrient deficiencies in soils and their redressal through SSNM with the following objectives: i) to assess the nature and extent of multi-nutrient inadequacies in the soils of mustard growing areas, and ii) to study the effectiveness of site-specific nutrient management (SSNM) in augmenting mustard productivity, farm profit and soil health under mustard-based cropping systems.

Materials and Methods

The study was comprised of soil fertility appraisal *vis-à-vis* on-farm experimentation on site-specific nutrient management (SSNM) to enhance the productivity, farm profit and soil health under mustard-based cropping system during 2007-2012.

Soil fertility appraisal and assessment of multi-nutrient deficiencies

Soil sampling

Soil samples from some important mustard growing agro-ecological sub-regions (AESRs) were collected. In all, 1601 soil samples (0-15 cm depth)

Table 1: Details of soil samples collected from important mustard 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	Haryana	Gurgaon	92
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			
9.1 Foothills of Kumaon Himalayas	Uttaranchal	Azampur, Saharanpur	92
9.2 Rohilkhand, Awadh and South Bihar Plain	Uttar Pradesh	Malikpur, Faizabad	106
		Tohfapur, Varanasi	100
12.3 Chhotanagpur Plateau	Jharkhand	Ranchi	101
13.1 North Bihar & Awadh Plain	Bihar	Ibrahimpur, Bhagalpur	100
Humid Per-humid ecosystem			
14.3 Himalayas Humid Per-humid	Himachal Pradesh	Kangra	106
15.1 Bengal Basin	West Bengal	Ghoragacha, Nadia	100
15.4 Upper Brahmaputra Plain	Assam	Deogharia lakheraj, Jorhat	100
17.1 Meghalaya Plateau & Nagaland Hills	Assam	Mithiphang, Karbi Anglong	104
Total			1601

were collected from 16 important mustard growing districts *i.e.* Jodhpur, Kota, Hisar, Gurgaon, Saharanpur, Faizabad, Kanpur, Varanasi, Banaskantha, Mehsana, Ranchi, Bhagalpur, Kangra, Nadia, Jorhat and Karbi Anglong, representing 14 AESRs (Table 1).

One village each in the selected AESRs representing predominant soil type and mustard based cropping systems of the AESR was selected 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). Available N in soil was computed based on organic carbon content of soil using standard equation. This equation is used in soil testing laboratory for assessing N status of soil and fertilizer recommendations.

For soil fertility evaluation, two categories *viz.* ‘fertilizer responsive’ and ‘fertilizer less 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 less-responsive. This modified soil fertility evaluation criterion was adopted in the light of a large number of the research reports indicating frequent 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 d” 0.75%, available P d” 25 kg ha^{-1}, available K d” 280 kg ha^{-1} and available S d” 22.5 kg ha^{-1} were placed in responsive category for N, P, K and S, respectively. The threshold levels for 1*N* NH_4OAc-extractable Ca and Mg were used as

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 less-responsive ones. Soils containing < 0.5 mg kg^{-1} of hot water soluble B were rated responsive to B application (Dwivedi *et al*., 2009).

The experiment sites to redressal multi-nutrient deficiencies through SSNM

One of the sampling sites *i.e.* 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 namely Siriska, Khaika, Daula, Abhaypur, Lakhuvas and Lohtaki to understand the cropping systems and farmers' crop management practices. Mustard is grown with NP fertilizers, but the use of K, S and micronutrients was largely ignored. As a result, average mustard 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. Village Lohtaki represented semi-arid climate of 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.

Experimental details

Twelve on-farm experiments with pearlmillet-mustard cropping system for two years 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 05 strips to impose 05 fertilizer treatments *i.e.* T_1: SSNM; T_2: State *ad-hoc* recommendation plus potassium (SR) + K; T_3: SR; T_4: Farmer's fertilizer practice (FFP) + K; and T_5: FFP. Fertilizer rates in SSNM 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 pearlmillet and 120+60+100 kg ha^{-1} in mustard. 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 alone in pearlmillet and 60 kg N + 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 80 kg N + 30 P_2O_5 + 250 kg gypsum ha^{-1}, respectively.

Hybrid pearlmillet cv. 'JKDH 676' and mustard cv. 'Pusa Bold' were used for the on-farm experiments. In these 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.

The Zn and B were applied to pearlmillet crop only, however, both crops received S in SSNM. Mustard crop also received S in 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. Both 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 followed standard procedure as described in Table 2. 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.) 11.5, 17.1, 9.2, 10.0, 35.0 and 25.0, respectively. The price (per tonne) of pearlmillet and mustard grain was Rs. 9300 and 21630 and that of straw/stover was Rs. 1500 and 1000, respectively. For the statistical analysis of the yield data, replicated data recorded, and the data of the on-farm experiments was analysed as per ANOVA of randomized block design.

Table 2: Standard procedures followed for soil analysis

Parameters	Analytical procedures	References
pH and EC	Soil:water (1:2) suspension	Page *et al.*, 1982
Organic C	Chromic acid digestion	Walkley and Black, 1934
Available P	0.5 *M* $NaHCO_3$ (pH 8.5)0.03 *N* NH_4F+0.025 *N* HCl	Olsen *et al.*, 1954Bray and Kurtz, 1945
Available K	1 *N* NH_4OAc (pH 7.0)	Hanway and Heidel, 1952
Available S	0.15 % $CaCl_2$	Williams and Steinbergs, 1969
Available Zn, Fe, Cu, Mn	0.005 *M* DTPA-TEA-$CaCl_2$ (pH 7.3)	Lindsay and Norvell, 1978
Available B	Hot water	Gupta, 1967

Results and Discussion

Soil fertility appraisal and multi-nutrient deficiencies

Soil samples from important mustard growing districts were analyzed for soil pH, EC, organic C, available N, P, K, S, Zn, Fe, Cu, Mn and B (Tables 1 and 3). 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 mustard growing agro-ecological sub-regions (AESRs). The prominent multi-nutrient deficiency combinations in soils of important mustard growing districts revealed that available status of a particular nutrient varied from place to place. Deficiency of maximum 6 nutrients was recorded in Gurgaon and Ranchi districts, 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 and micronutrients, particularly of S and Zn. Occurrence of such multi-nutrient deficiency may be ascribed to soil properties, management practices, prevailing

Table 3: Nature and extent of multi-nutrient deficiencies in soils of important mustard rowing 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)
4.2	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)
9.1	Saharanpur	Azampur	SZnB (11%), SZn (5%) and KSZn (4%)
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)
12.3	Ranchi	Barhu	NPKSZnB(18), NPKSZn(15), NPKSZnCa(11)
13.1	Bhagalpur	Ibrahimpur	NK(55), NPKZn(14), NPK(8)
14.3	Kangra	Manjherna	PK(29), NK(12), NPKZn(5)
15.1	Nadia	Ghoragacha	NKB(35), NK(21), NKS(9) NKZnB(8)
15.4	Jorhat	Deogharia lakheraj	NPKB(24), PK(20), NKB(19)
17.1	Karbi Anglong	Mithiphang	NPKB (26), NPK (18), PKB (12)

cropping systems and climate conditions. Such contention can derive support from earlier findings of researchers (Yadav and Meena, 2009; Rathod *et al*., 2012; Meena *et al*., 2012; Dey *et al*., 2013; Mandal *et al*., 2013).

On-farm experiments on SSNM in pearlmillet-mustard system: A case study

Village Lohtaki (Gurgaon) was located in North Punjab Plain and Ganga-Yamuna Doab (AESR 4.1), and 92 soil samples were collected and analyzed for important properties including available plant nutrient contents. In Lohtaki, 12 field experiments were conducted to assess the effect of SSNM practices on soil health and productivity of pearlmillet-mustard cropping system. Results are described below

Soil properties

Soil pH varied from 7.25 to 8.74 (mean 7.66) indicating that the soils were neutral to mildly alkaline in reaction. None of the samples exhibited soil salinity. In fact, groundwater used for irrigation in the village was also non-saline. Out of 92 samples, about 80% soil samples fall under loamy sand and remaining comes under sandy textural class (data not shown) indicating that these soils are light in texture. Light texture soils are usually deficient in nutrients.

Available nutrient content

Range and mean values of available nutrients including organic C are presented in table 4. Widespread deficiencies of N (assessed in terms of organic C), K, S, and B were recorded in these soils. Nearly all the samples contained organic C in the responsive range, while 52 and 83% samples were placed in K and S responsive categories, respectively. Deficiency of P was of relatively lesser magnitude as only 14% samples fell under responsive category. Of the DTPA extractable micronutrients, Zn and Cu deficiencies were noted in 38 and 20% samples, respectively. The extent of B deficiency was 34%, which was unusual for the alluvial soils of semi-arid climate. This was obviously due to excessive mining of soil B by crops grown on light texture soils and continuous neglect of soil testing to ascertain B deficiency.

Multi-nutrient deficiencies

The soils were so exhausted of plant nutrients that simultaneous deficiencies of 2 to 5 nutrients were frequently observed. More than twenty multi-nutrient deficiency combinations were noticed of which NKS (16%), NS (12%), NSB (11%) and NKSZnB (7%) were the prominent ones (Fig. 2). Such deficient soils are pre-requisite for conducting field trials on assessing efficacy of SSNM packages

Table 4: Available nutrient content in soils of village Lohtaki, district Gurgaon

Soil parameters	Fertilizer responsive category			Fertilizer Less-responsive category		
	No. of	Range samples	Mean	No. of samples	Range	Mean
Oragnic C (%)	90	0.09-0.46	0.25	2	0.56-0.58	0.57
Available P (kg/ha)	14	0.90-9.86	6.72	78	10.3-74.8	25.8
Available K (kg/ha)	48	49.5-119	97.0	44	121-750	208
Available Ca (cmol/kg)	-	-	-	92	2.50-8.63	4.79
Available Mg (cmol/kg)	-	-	-	92	2.58-5.27	3.90
Available S (kg/ha)	76	1.65-21.9	13.3	16	22.8-39.4	28.0
DTPA -Zn (mg/kg)	35	0.24-0.76	0.56	57	0.81-3.23	1.41
DTPA- Fe (mg/kg)	2	3.20-4.30	3.75	90	4.9-15.5	8.33
DTPA- Cu (mg/kg)	18	0.09-0.20	0.16	74	0.21-1.40	0.36
DTPA- Mn (mg/kg)	-	-	-	92	9.34-21.1	15.0
Available B (mg/kg)	31	0.14-0.46	0.32	61	0.52-3.60	1.19

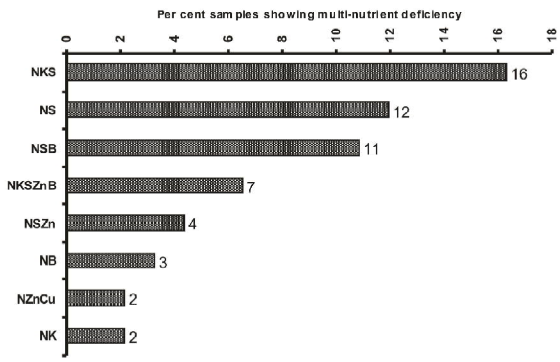


Fig 2. Extent of multi-nutrient deficiency in soils of village Lohtaki, district Gurgaon

in enhancing productivity of crops and cropping systems. It is expected that there will be spectacular response of crops to applied nutrients.

Productivity of pearlmillet-mustard system

Pearlmillet

Across the experiments (farmers' fields), grain yield ranged between 2.10 and 4.33 t ha^{-1}, with the lowest in FFP and the highest in SSNM (Table 5). On an average, SR+K, *i.e.* SR supplemented with fertilizer K_2O produced, an additional yield of 0.44 t ha^{-1} over SR. Yield responses over FFP were the highest in SSNM (71%), followed by SR+K (49%) and SR (30%). More or less similar responses of crops to applied nutrients were earlier reported by Meena et al. (2008a, b), Rathod *et al*. (2012) and Meena *et al*. (2013).

Table 5: Grain yield of pearlmillet under pearlmillet-mustard cropping system as influenced by different fertilizer options (average of 2 years)

Farmer's name	Treatments				
	SSNM	SR+K	SR	FFP+K	FFP
Sh. Likhi	3.80	3.35	2.87	2.69	2.32
Sh. Prem	4.25	4.12	3.25	2.96	2.73
Sh. Hardey	4.33	3.35	2.98	2.83	2.50
Sh. Bahadur	3.85	3.18	2.77	2.68	2.22
Sh. Omvir	4.18	3.65	3.05	2.76	2.30
Sh. Chandi	3.87	3.48	2.95	2.45	2.10
Minimum	3.80	3.18	2.77	2.45	2.10
Maximum	4.33	4.12	3.86	2.96	2.73
Mean	4.05	3.52	3.08	2.73	2.36
STDEV	0.17	0.23	0.14	0.16	0.10
Sustainability Index	0.89	0.80	-	-	-

Mustard

On an average, grain yield of mustard grown after pearlmillet under SSNM was 2.88 t ha^{-1}, which was about double of that recorded under FFP (Table 6). Yield gain in terms of per cent response under SSNM over FFP was relatively greater in mustard than that in pearlmillet across the experiments. On an average, grain yield responses over FFP across the experiments were the highest in SSNM (85%), followed by SR+K (40%) and SR (24%). This is ascribed to the balance nutrition in case of SSNM. Although mustard is not known to be responsive to fertilizer K as cereals, yet inclusion of K in FFP or SR increased its grain yield to the tune of 0.15 to 0.62 t ha^{-1}. This is possibly related to low K content of soils in experimental sites. This is reflected well in sustainability index of SSNM and SR+K treatments. Meena *et al*. (2006c) and Meena *et al*., (2008) reported very good response of mustard to applied secondary and micronutrients.

Effect on soil fertility status

Analysis of post harvest soil samples (0-15 cm) after completion of two cropping cycles revealed only a marginal improvement in organic C content under SSNM over the initial content across the experiments

Table 6. Grain yield of mustard under pearlmillet-mustard cropping system as influenced by different fertilizer options (average of 2 years)

Farmer's name	Treatments				
	SSNM	SR+K	SR	FFP+K	FFP
Sh. Likhi	2.82	2.25	1.96	1.72	1.51
Sh. Prem	3.11	2.20	2.08	1.76	1.70
Sh. Hardey	2.80	2.15	1.82	1.70	1.44
Sh. Bahadur	2.94	2.35	1.90	1.80	1.65
Sh. Omvir	2.85	2.04	1.80	1.60	1.48
Sh. Chandi	2.76	2.10	1.92	1.68	1.59
Minimum	2.76	2.04	1.80	1.60	1.44
Maximum	3.11	2.35	2.18	1.80	1.70
Mean	2.88	2.18	1.93	1.71	1.56
STDEV	0.09	0.15	0.06	0.09	0.10
Sustainability Index	0.90	0.87	-	-	-

(Fig. 3). Such marginal change is due to addition of organic matter mainly through higher root biomass and left-over above ground parts of crops in SSNM as compared to other treatments. Since no treatment

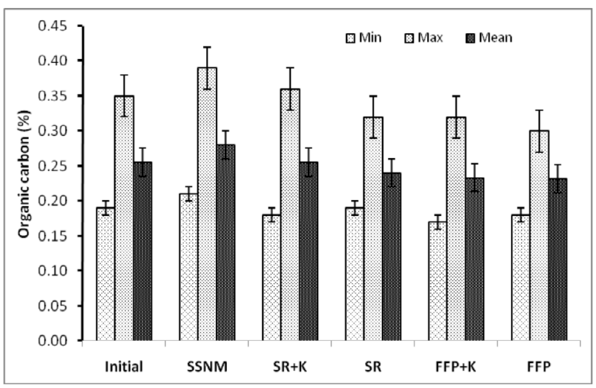


Fig 3: Soil organic C in on-farm experiments after mustard under pearlmillet-mustard cropping system

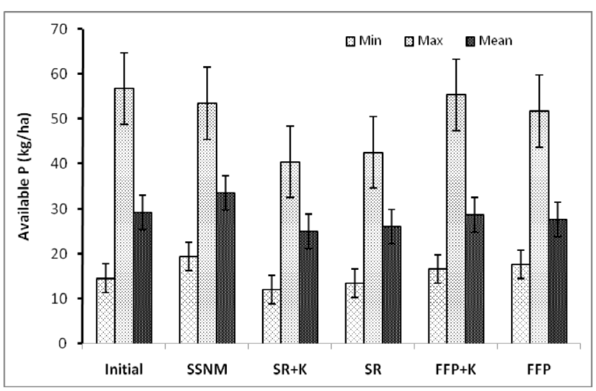


Fig 4: Available P in on-farm experiments after mustard under pearlmillet-mustard cropping system

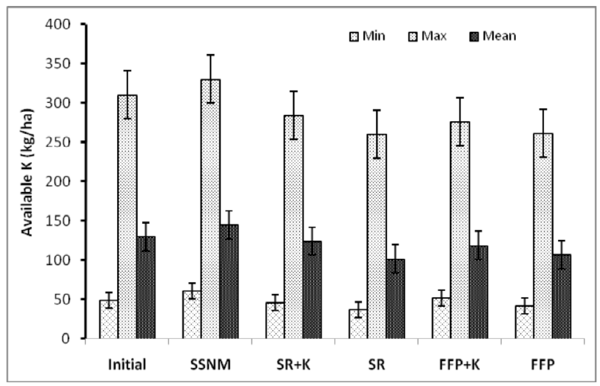


Fig 5: Available K in on-farm experiments after mustard under pearlmillet-mustard cropping system

included organic manures much change in organic C status should not be expected in light textured soils under tropical climate conditions. Treatment effects, on the other hand, were more spectacular with respect to available P and K contents across the experiments (Fig. 4 and Fig. 5). On average, soil available P under SSNM was greater than the initial content by 5 kg ha^{-1} in post-mustard samples, whereas a depletion of about 4 kg P/ha under SR+K in post-mustard samples was recorded (Fig. 4). In post-mustard analysis, available K content registered an average increase (over the initial value) of about 15 kg ha^{-1} in SSNM treatment. The K content, however, got depleted in FFP and SR treatments, and the magnitude of such depletion was 6-28 kg ha^{-1} (Fig. 5). These treatment effects could be explained in the light of differential K requirement

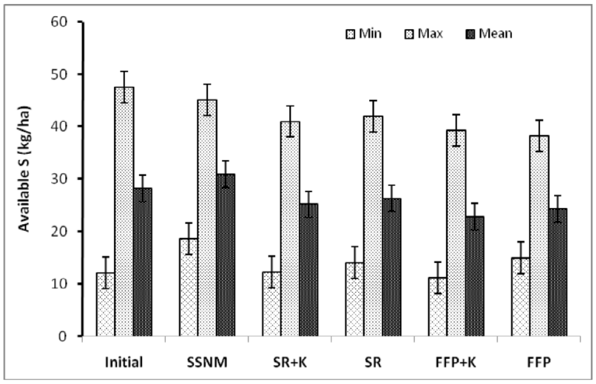
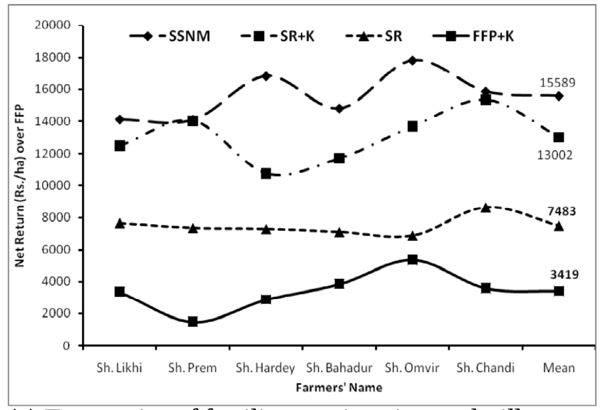


Fig 6: Available S in on-farm experiments after mustard under pearlmillet-mustard cropping system

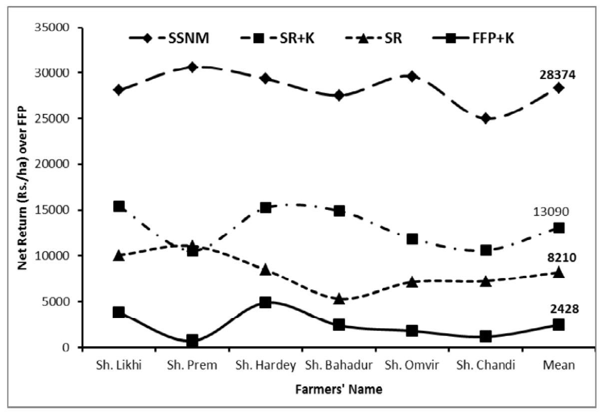
of crops (Majumdar *et al*., 2012). Available S content of post-mustard soil was fairly maintained at the initial level in SSNM treatment, whereas an average decline of 2.0 to 5.2 kg ha^{-1} compared with the initial content was recorded in other treatments (Fig. 6). Relatively higher soil S content 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 03 treatments *i.e.* SSNM, SR and SR+K. Changes in nutrient status in post-harvest soils is in concurrence with nature of treatments imposed in preset studies.

Economics of SSNM vis-à-vis other fertilizer practices

Based on the yield response data, economics of different fertilizer options over FFP was worked out (Fig.7a & b). On an average, net return over FFP in pearlmillet-mustard cropping system, was higher (Rs. 43963 ha^{-1}) under SSNM, followed by SR+K (Rs. 26092 ha^{-1}) and SR (Rs. 15693 ha^{-1}). Supplementing K only to the farmers' fertilizer practices (FFP) could be increased the net-returns over the FFP (Majumdar *et al*., 2012; Meena *et al*., 2012). Profits increased substantially consequent to adoption of improved fertilizer practices *i.e.* SSNM. Between the two crops, adoption of SSNM in mustard was far more profitable than that of pearlmillet (Fig. 7). This is attributed to higher economic value of oilseed crop over that of cereal. Besides, additional yield obtained in case of SSNM was more uniform across the farmers' fields in case of mustard than pearlmillet. Another reason is relatively higher response of mustard to SSNM



(a) Economics of fertilizer options in pearlmillet over FFP



(b) Economics of fertilizer options in mustard over FFP

Fig 7: Net economic returns of pearlmillet-mustard system under different(a,b) fertilizer options *vis-à-vis* FFP in the on-farm experiments

practices over other nutrient supply options. Results of these on-farm experiments thus clearly established the significance of SSNM, in improving crops yield and economic returns on one hand, and restoration soil fertility on the other.

Conclusions

Widespread deficiencies of six nutrients, namely N, P, K, S, Zn and B have been emerged in the soils of mustard growing agro-ecological sub-regions (AESRs). Such deficiencies would not only affect crop productivity but also enhance the pace of nutrient mining from native reserves of soils aggravating the severity deficiencies. Superiority of soil test-based site-specific nutrient management (SSNM) is established beyond doubt over other options in augmenting the crop yields, economic returns and soil health. It can be concluded that productivity of crops like mustard could be almost doubled with the adoption of soil test-based SSNM that will help in achieving the goal of self sufficiency in edible oil.

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