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Soil test crop response based fertilizer recommendations under integrated nutrient management for higher productivity of pearl millet (*Pennisetum glaucum*) and (*Triticum aestivum*) wheat under long term experiment

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ABSTRACT

Field experiments were conducted to assess the soil test crop response (STCR) based fertilizer requirements for pearl millet–wheat sequence under integrated nutrient management (INM) under long term field experiment since 2003 at IARI, New Delhi. The results indicated that the STCR based fertilizer with 10 tonnes FYM/ha recorded highest mean grain (3.62 and 6.13 tonnes/ha) and stover/straw (7.0 and 8.01 tonnes/ha) yields of pearl millet (*Pennisetum glaucum* L. R. Br) and wheat (*Triticum aestivum* L.), which were 123.4 and 104.3 % higher in term of grain yield over control, respectively. STCR based fertilizer with 5 tonnes FYM/ha, STCR based chemical fertilizer and RDF treatments were statistically at par with respect to yield of pearl millet and wheat. Higher system grain yield (9.74 tonnes/ha) of pearl millet–wheat cropping system was recorded with STCR based integrated use of fertilizer with 10 tonnes FYM/ha. Nutrients uptake by pearl millet and wheat were significantly higher in STCR based fertilizer with 10 tonnes FYM/ha as compared to other treatments. Available N, P and K status in post-harvest soil was improved significantly with 20 tonnes FYM/ha alone as compared to other treatments but statistically at par with STCR based fertilizer with 10 tonnes FYM/ha. The long term study based on STCR clearly demonstrated that STCR based integrated use of fertilizer for targeting yield can produce targeted yield of crops and save the fertilizer without impairing soil fertility.

Key words: Integrated nutrient management, Nutrient uptake, Pearl millet-wheat, Stest based fertilizer use, Soil fertility

Pearl millet (*Pennisetum glaucum* L. R. Br) - wheat (*Triticum aestivum* L.) cropping system is most important system under irrigated condition in arid and semi arid tropical climate of India. This cropping system is followed in an estimated area of 2.26 million ha in India (Moharana *et al.* 2012). This cropping system is very exhaustive and a crop yield 2.9 tonnes of pearl millet and 4.2 tonnes /ha of wheat may remove 238, 54 and 131 kg nitrogen (N), phosphorus (P) and potassium (K), respectively. At present, nutrient mining is a major threat for agricultural soil as there is wide gap between nutrient addition and nutrient removal, one of the reasons for lower production is imbalanced use of fertilizer by the farmers without knowing soil fertility status and nutrient requirement of crop causes adverse effect on soil and crop both in terms of nutrient toxicity and deficiency. In India like country, farmers' using excess chemical fertilizer to get higher yield but the decision on fertilizers demand by crop needs knowledge of the expected crop yield and response to nutrient application. This practice not only deteriorates the soil health but also led to economical loss of farmers. There is an enormous scope to increase the productivity of pearl millet and wheat grown in sequence based on soil test crop response (STCR) approach. In this approach, the fertilizer doses are recommended based on fertilizer adjustment equations which are developed after establishing significant relationship between soil test values and the added fertilizers. Recommendation based on STCR correlation concept are more quantitative, precise and meaningful because it involves combined use of soil and plant analysis, which provide information on real balance between applied nutrient and available nutrients of soil. Alternatively, organic manure is a valuable and renewable nutrient source, but their application alone to soils is not adequate to meet the nutrient demand of the modern varieties of the crop and resulted in poor yield of the crops. Nevertheless, their continuous application enhances not only the biological activity and their biomass, diversity and soil physical properties but also enhances resistance and resilience capacity of soil (Sharma *et al*. 2015, Kumar *et al.*

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2014). Therefore, integration of inorganic with organics may go long way in maintaining sustainable crop production and enhancing soil health through their complementary effects (Antil *et al.* 2011). Therefore, there is a need to improve nutrient supply system in term of balanced nutrient management involving soil test crop response (STCR) based integrated use of fertilizer in conjunction with farmyard manure and chemical fertilizer through soil test process. The present study was, therefore, under taken to assess the effect of soil test crop response based fertilizer recommendations for pearl millet-wheat crop sequence under integrated nutrient management.

MATERIALS AND METHODS

A long term STCR based fertilizer recommendations experiment was started during *kharif*-2003 at Indian Agricultural Research Institute, New Delhi using pearl millet–wheat cropping sequence. The treatments details were T_1; Control, T_2 ; 20 tonnes FYM/ha alone , T_3 ; STCR based integrated fertilizer dose with 10 tonnes FYM/ha (3.5 and 6.0 tonnes/ha targeted grain yield of pearl millet and wheat, respectively), T_4; STCR based chemical fertilizers (3.5 and 6.0 tonnes/ha targeted grain yield of pearl millet and wheat, respectively), T_5; RDF of the crops and T_6; STCR based integrated fertilizer dose with 5 tonnes FYM (3.5 and 6.0 tonnes/ha targeted grain yield of pearl millet and wheat, respectively). The treatments T_5 and T_6 in experiment were included in *kharif*-2012. The experiment was laid out in randomized block design with four replications. Nutrients doses (kg/ha) were calculated from the fertilizer adjustment equations for targeting yield 3.5 and 6.0 tonnes/ha of pearl millet and wheat crop, respectively. The fertilizer adjustment equations are given below:

Pearl millet crop	
Without FYM	With FYM
FN = 69.7 T - 0.36 SN	FN = 53.5 T - 0.29 SN - 2.23 FYM
FP_2O_5 = 57.3 T - 4.81 SP	FP_2O_5 = 47.2 T - 3.29 SP - 2.48 FYM
FK_2O = 39.2 T-0.28 SK	FK_2O = 28.8 T-0.17 SK-1.35 FYM
Wheat crop	
Without FYM	With FYM
FN = 43.0 T - 0.44 SN	FN = 38.5 T - 0.41 SN - 1.64 FYM
FP_2O_5 = 37.9 T - 6.02 SP 1.72	FP_2O_5 = 27.8 T - 4.12 SP - FYM
FK_2O = 23.4 T - 0.33 SK	FK_2O = 20.4 T - 0.29 SK-0.88 FYM

where (FN, FP_2O_5 and FK_2O = fertilizer dose (kg/ha) and (SN, SP and SK = soil test values (kg/ha), T stand for targeted yield of the crop in tonnes/ha, FYM tonnes/ha and amount of N added through DAP was adjusted.

Calculated amount of nitrogen was applied as per treatments through urea. Half dose of nitrogen was applied as basal at sowing and remaining half in two equal splits at tillering and heading of wheat crop and 15 days after sowing and knee high stage (45 days after sowing) in pearl millet. Phosphorus and potash was added as per treatments through DAP and muriate of potash as basal dose at the time of sowing of pearl millet and wheat. The required quantity of FYM was applied two weeks before swing of the crop as per treatment. The pearl millet crop was sown during the first week of July while sowing of wheat was done in the month of November during 2012 and 2013. The irrigations were given as per need of the crops and two hand weedings were done for removing the weeds from experimental field. The yields (grain and straw of both crops) were recorded at harvest. The soil samples collected after harvest of each crop were analyzed for available nitrogen by alkaline permanganate method (Subbaiah and Asija 1956), available phosphorus (Olsen *et al*. 1954) and available potassium by ammonium acetate method (Hanway and Heidal 1952). The plant samples (grain and straw) were collected at the harvest of both the crops. Kjel plus (nitrogen analyzer) instrument was used to determine nitrogen content in wheat grain and straw after digestion of samples with sulphuric acid using catalyst mixture (potassium sulphate and copper sulphate). Phosphorus content was estimated in digested samples with diacid (HNO_3:$HClO_4$ :: 3:1 ratio) by Vanadomolybdo-phosphoric yellow color method and potassium by flame photometer. Statistical methods (Gomez and Gomez 1984) were used for analyzing the data. The uptake of nutrients was obtained as product of their concentrations and yield.

RESULTS AND DISCUSSION

Growth and yield attributes

The plant height, biomass, ear length and grain weight of pearl millet were significantly influenced by soil test crop response (STCR) based fertilizer application (Table 1). Plant height (189.4 and 192.1 cm) and dry matter accumulation (42.4 and 44.2 g/plant) of pearl millet were recorded significantly higher with application of 20 tonnes FYM /ha alone as compared to recommended dose of fertilizer (T_5) and control treatments. The STCR based fertilizer with 10 tonnes FYM/ha (T_3), STCR based chemical fertilizer (T_4) and STCR based fertilizer with 5 tonnes FYM (T_6) were statistically at par in respect of plant height and biomass accumulation. However, application of STCR based fertilizer with 10 tonnes FYM/ha recorded significantly higher grain weight (40.7 and 41.4 g/ear in 2012 and 2013, respectively) as compared to recommended dose of fertilizer (33.7 and 34.7 g/ear).

The STCR based fertilizer with 10 tonnes FYM/ha recorded significantly higher plant height (97.9 and 93.2 cm), effective tillers (93.2 and 93.3), spike length (9.9 and 9.9 cm), grains/spike (53.5 and 53.9) and 1 000 grain weight (46.3 and 46.0 g) of wheat over recommended dose of fertilizer and control treatments during 2012-13 and 2013-14, respectively (Table 3). Soil test based fertilizer with 10 tonnes FYM/ha resulted in an additive effect on these yield attributes. Other treatments, FYM alone (T_2),

Table 1 Effect of integrated fertilizer use based on soil test crop response on growth and yield contributing characters of pearl millet

Treatment	Plant height(cm)		Dry matter accumulation/ plant (g)		Ear length(cm)		Grain weight/ear(g)	
	2012	2013	2012	2013	2012	2013	2012	2013
T_1	154.9	156.5	28.8	29.6	24.4	24.8	27.5	28.4
T_2	189.4	192.1	42.4	44.2	26.2	26.5	39.8	40.5
T_3	183.5	185.4	41.5	42.7	26.9	27.2	40.7	41.4
T_4	177.3	179.0	40.0	41.2	25.7	26.2	38.8	39.3
T_5	167.5	170.0	36.4	37.9	25.2	25.8	33.7	34.7
T_6	180.9	182.4	39.2	40.7	25.9	26.4	39.3	39.1
SEm ±	1.91	2.31	1.74	1.67	0.74	0.63	1.51	0.88
CD (P=0.05)	5.82	7.02	5.28	5.08	NS	NS	4.59	2.66

STCR based chemical fertilizer (T_4), STCR based with 5 tonnes FYM/ha (T_6) and recommended dose of fertilizer (T_5), being at par in respect of growth and yield attributes but, recorded significantly higher growth and yield attributes over control. The increase in growth and yield attributes may be due to increased availability of nutrients to plants initially through fertilizers and then by FYM. In addition to supply nutrients, FYM also improves physical conditions of soil especially under light textured sandy loam soil. The increase in growth parameters of pearl millet through integrated nutrient management were also attributed by Singh *et al*. (2014).

Table 2 Effect of integrated fertilizer use based on soil test crop response on yield of pearl millet

Treatment	Grain yield (tonnes/ha)		Pooled yield	% response	Stover yield (tonnes/ha)		Pooled yield
	2012	2013			2012	2013	
T_1	1.45	1.78	1.62	-	3.91	4.02	3.97
T_2	2.64	2.78	2.71	67.3	6.35	6.51	6.43
T_3	3.57	3.66	3.62	123.4	6.88	7.11	7.00
T_4	3.25	3.18	3.22	98.7	6.15	6.37	6.26
T_5	3.20	3.01	3.11	91.9	5.93	6.29	6.11
T_6	3.44	3.34	3.39	109.3	6.63	6.84	6.74
SEm ±	0.07	0.079			0.13	0.11	
CD (P=0.05)	0.21	0.24			0.39	0.34	

Yield

STCR based use of fertilizer 10 tonnes FYM/ha recorded significantly higher grain and straw yield of pearl millet (3.57 and 3.65, mean 3.62 tonnes/ha) and (6.88 and 7.11, mean 7.00 tonnes/ha) during 2012 and 2013 as compared to other treatments (Table 2) and achieved the targeted yield of pearl millet (3.5 tonnes/ha). Other treatments, i.e. STCR based use of chemical fertilizer (T_4), recommended dose of fertilizer (T_5) and STCR based fertilizer with 5 tonnes FYM/ha (T_6) were statistically at par with each other in respect of grain and straw yield of pearl millet. On the basis of pooled data, STCR based use of fertilizer with 10 tonnes FYM/ha and 5 tonnes/ha recorded higher grain yield by 12.4% and 5.3% and straw by 11.8% and 7.7%, respectively over STCR based chemical fertilizer. Higher response rate (123.4%) was also observed with STCR based fertilizer with 10 tonnes FYM/ha than STCR based fertilizer with 5 tonnes FYM/ha (109.3%) over control in term of grain yield of pearl millet. This might be due to supply of the nutrients in balanced amount and slowly release of nutrients through integration use of FYM which helped to produce more numbers of grains/ear and ear length. Application of 20 tonnes FYM/ha alone produced less pearl millet yield (2.64 and 2.78 tonnes/ha) during both the years as compared to rest of other treatments except control. Sharma *et al.* (2015) also reported similar results in pearl millet crop.

Application of STCR based fertilizer with 10 tonnes FYM/ha significantly increased the grain and straw yield of wheat as compared to other treatments (Table 4). Integrated

Table 3 Effect of STCR based fertilizer recommendations for targeted yield on growth and yield attributes of wheat

Treatment	Plant height(cm)		Effective tillers/ m		Spike length(cm)		Grains /spike		1000-Grain weight (g)	
	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14
T_1	80.5	70.0	58.1	58.5	8.6	8.5	47.7	48.8	38.4	39.6
T_2	92.9	85.0	84.3	80.8	9.3	9.2	52.5	50.4	43.9	44.6
T_3	97.9	93.2	93.2	93.3	9.9	9.9	53.5	53.8	46.3	46.0
T_4	97.1	87.7	88.0	88.0	9.2	9.2	50.6	51.0	41.1	43.4
T_5	95.0	84.9	87.2	87.5	8.9	8.9	48.5	49.1	39.9	41.2
T_6	96.7	85.2	89.7	90.8	9.2	9.1	50.3	51.1	41.0	42.5
SEm ±	1.25	1.32	2.49	2.92	0.27	0.24	1.96	1.66	1.16	1.20
CD (P=0.05)	NS	4.02	7.59	8.88	NS	0.75	NS	NS	3.54	3.65

Table 4 Effect of integrated fertilizer use based on soil test crop response on yield of wheat and system productivity

Treatment	Grain yield (tonnes/ha)		Pooled yield	% response	Straw yield (tonnes/ha)		Pooled yield	System grain yield (tonnes/ha)		
	2012-13	2013-14	(tonnes/ha)		2012-13	2013-14	(tonnes/ha)	2012-13	2013-14	Mean
T_1	2.99	3.01	3.00	-	3.98	3.94	3.96	4.44	4.79	4.62
T_2	4.73	4.67	4.70	56.7	5.92	5.85	5.89	7.37	7.45	7.41
T_3	6.28	5.97	6.13	104.3	8.24	7.95	8.01	9.85	9.63	9.74
T_4	5.70	5.49	5.60	86.7	6.98	6.88	6.93	8.95	8.67	8.81
T_5	5.56	5.53	5.55	85.0	6.54	6.33	6.44	8.76	8.54	8.65
T_6	5.74	5.64	5.69	89.7	6.84	6.68	6.76	9.18	8.98	9.08
SEm ±	0.09	0.10			0.14	0.22				
CD (P=0.05)	0.26	0.30			0.43	0.67				

use of fertilizer with 10 tonnes FYM/ha based on STCR recorded significantly higher grain and straw yield (6.28 and 5.97 tonnes/ha, mean 6.13 tonnes/ha) and (8.24 and 7.95 tonnes/ha, mean 8.01 tonnes/ha) as compared to other treatments. Based on pooled data, STCR based fertilizer with 10 tonnes FYM/ha recorded higher grain yield by 9.5% over STCR based chemical fertilizer. The treatments STCR based chemical fertilizers (T_4), recommended dose fertilizer (T_5) and STCR based fertilizer with 5 tonnes FYM (T_6) were statistically at par in respect of grain yield, but these treatments recorded significantly higher grain as well as straw yield of wheat over the FYM alone (T_2) and control. Higher response rate (104%) in respect of grain yield was also noticed with STCR based use of fertilizer with 10 tonnes FYM/ha (T_3) over control. This might be due to enhanced microbial activity, conversion of unavailable nutrients in to available forms and also due to improved physical, chemical and biological properties (Sharma *et al.* 2015) that lead to the increased productivity. The higher yield of wheat seemed to be the cumulative effect of yield attributes which was boosted by balanced nutrient supply (Yaduvanshi *et al.* 2013).

Nutrients uptake

The pooled data on total N, P and K uptake by pearl millet and wheat are given in Table 5. Soil test based fertilizer use with FYM, and FYM alone significantly improved the total uptake of N, P and K in peal millet and wheat as compared to control. The total uptake of nitrogen by pearl millet (108.3 kg/ha) and wheat (158.6 kg/ha) were significantly higher with soil test based fertilizer use with 10 tonnes FYM/ha as compared to other treatments which might be due to release of N as a result of decomposition of FYM. Addition of organic matter increased the microbial population which resulted in the enhanced availability of nitrogen. The total uptake of P by pearl millet (18.0 kg/ha) and wheat (60.1 kg/ha) increased significantly with FYM application over control, which may be associated with physiological stimulation of plant rather than increase ramification of root system (Chandel *et al.* 2013). The highest phosphorus uptake of 22.8 kg/ha by pearl millet and 79.3 kg/ha by wheat were recorded with soil test based fertilizer with 10 tonnes FYM/ha, indicating higher assimilation and uptake of P due to combined application of FYM with inorganic fertilizer. However, the phosphorus uptake by pearl millet and wheat due to application of soil test based chemical fertilizer use (T_4) and soil test based fertilizer use with 5 tonnes FYM/ ha (T_6) treatments were statistically at par with each other but significantly superior to 20 tonnes FYM/ha alone and recommended dose of fertilizer (T_5) treatments. The lowest uptake of (8.0 kg/ha) by pearl millet and 37.0 kg/ha by wheat was recorded in the control. The highest K uptake by pearl millet (184.3 kg/ha) and wheat (152.5 kg/ha) was obtained under STCR based

Table 5 Total uptake of nutrients by pearl millet and wheat (mean of two years) and post-harvest soil fertility status

Treatment	Total nutrient uptake (kg/ha)						Available nutrients (kg/ha)		
	Pearl millet			Wheat					
	N	P	K	N	P	K	N	P	K
T_1	33.9	8.0	85.7	74.0	37.0	59.9	158	21.1	195.5
T_2	82.2	18.0	153.1	120.2	60.1	108.6	235	35.9	288.8
T_3	108.3	22.8	184.3	158.6	79.3	152.5	229	34.6	280.8
T_4	90.6	19.1	157.8	138.2	69.1	125.1	200	32.1	235.8
T_5	84.0	16.7	145.9	133.6	66.8	108.0	196	27.6	225.8
T_6	94.9	19.6	168.5	140.1	70.0	126.6	203	29.4	215.0
SEm ±	2.03	1.31	2.39	1.59	0.36	2.61	5.42	1.59	3.90
CD (P=0.05)	6.20	3.97	7.28	4.76	1.11	7.95	16.49	4.82	11.87

fertilizer use with 10 tonnes FYM/ha (T_3) and minimum in control. STCR based fertilizer application for targeted yield treatments had significantly higher K uptake by pearl millet and wheat crop over RDF, FYM alone application and control. Total K uptake by pearl millet and wheat significantly increased with addition of STCR based fertilizer with 10 tonnes FYM/ha as compared to other treatments. The increase in uptake of nutrient by pearl millet and wheat with integrated application of nutrients may be due to improvement of the soil environment which encouraged proliferation of roots resulting in more absorption of water and nutrients from larger area and depth. Moreover, FYM after decomposition released nutrients which became available to the plants and thus increased NPK concentration. The higher nutrients uptake with FYM might be attributed to solubilisation of native nutrients chelation of complex intermediate organic molecules produced during decomposition of added FYM, its mobilization and accumulation of different nutrient in different plant parts (Kumar *et al.* 2014).

Soil fertility

Application of soil test based fertilizer along with 10 tonnes FYM/ha significantly increased the available N content in post-harvest soil over recommended dose of fertilizer and soil test based chemical fertilizer. The higher amount of available nitrogen (235 kg/ha) was noted with 20 tonnes FYM/ha in each crop, but both T_2 and T_3 treatments were statistically at par with each other in respect of available nitrogen status. However, rest of the treatments also significantly improved the available nitrogen status over control (Table 5). Increase in available nitrogen content with FYM alone or with STCR + 10 tonnes FYM/ha may be attributed to enhanced mineralization of FYM which might be helped in build up of available nitrogen (Yaduvanshi *et al.* 2013). The available phosphorus content in soil increased with FYM alone, STCR based fertilizer along with 10 tonnes FYM/ha and STCR based chemical fertilizer as compared to control. However, FYM alone and STCR+10 tonnes FYM/ha did not differ significantly with STCR based chemical fertilizer treatment in respect of available phosphorus. Application of 20 tonnes FYM/ha alone in each crop being at par with STCR + 10 tonnes FYM/ha recorded significantly higher available phosphorus over STCR based fertilizer + 5 tonnes FYM/ha and recommended dose of fertilizer. The increases in available phosphorus content in soil due to addition of farmyard manure may be due to its solubilising effect of native P. The maximum available K content (288.8 kg/ha) was recorded with 20 tonnes FYM/ha in each crop. Application of STCR based fertilizer along with 10 tonnes FYM/ha significantly increased the available K content in soil as compared to other treatments. Application 20 tonnes FYM/ha alone (T_2) and STCR based fertilizer with 10 tonnes FYM/ha (T_3) were statistically at par with each other in respect of available K content. Addition of FYM alongwith inorganic fertilizers had a beneficial effect in increasing the K availability. Similar results were reported by Sharma *et al.* (2015).

System productivity

Data on system productivity (Table 4) showed that the higher total grain productivity of pearl millet – wheat cropping system (9.85 and 9.63 tonnes/ha was recorded with soil test based fertilizer with 10 tonnes FYM/ha during 2013 and 2014 , respectively. STCR based fertilizer use with integration of 10 tonnes FYM/ha performed better and it was followed by STCR based fertilizer with 5 tonnes FYM/ha treatment. This may be due to application of soil test based balanced amount of fertilizer with FYM, which enhanced microbial activity, conversion of unavailable nutrients to available forms and also improved physical, chemical and biological properties that lead to the increased system productivity (Katkar *et al.* 2011). In general, total system yield was almost similar to RDF and STCR based fertilizer with 5 tonnes FYM/ha, when STCR based chemical fertilizers (3.5 and 6.0 tonnes/ha) targeted grain yield of pearl millet and wheat, respectively) was applied to the crops. Lowest system productivity was obtained with FYM alone application. The results are in conformity with Priyadarshani *et al.* (2012), who advocated the balanced use of fertilizer combination with FYM is necessary for sustaining the higher productivity of pearl millet based cropping system.

It may be concluded from the present study, that STCR based fertilizer recommendation along with 10 tonnes FYM/ha not only produced the targeted yield of pearl millet and wheat but also improved the soil fertility as compared to application of chemical fertilizer alone. Thus, STCR based fertilizer along with FYM can play a vital role in exploiting high yield potential of pearl millet-wheat crop sequence through its beneficial effect on nutrients supply and soil properties.

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