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Effect of Long-term Integrated Nutrient Management on Productivity of Pearl millet (*Pennisetum glaucum*) - Mustard (*Brassica juncea*) Cropping System and Soil Fertility in an Inceptisol

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The effect of varying levels of plant nutrients on pearl millet (*Pennisetum glaucum*) – mustard (*Brassica juncea*) cropping system productivity and available nutrients during 2003–2013 is being studied in an Inceptisol at Gwalior under the long-term permanent manurial trial. The results revealed that the application of recommended levels of NPK to pearl millet and mustard with organic manure (10 t FYM ha^{-1} yr^{-1}) and biofertilizers (*Azotobacter* and phosphate solubilizing bacteria, PSB) resulted in 100.9 and 130.2 per cent increase over control in pearl millet and mustard yields, respectively. Increasing levels of NPK from 50 to 150% significantly increased the yield of both the crops. Integrated use of organic, inorganic and bio-fertilizers improved the soil status of available N and P by 83 and 20.3 kg ha^{-1}, over the initial values. A declining trend (37 to 101 kg ha^{-1}) from the initial value of available K (250 kg ha^{-1}) was also recorded as a result of continuous cropping which was prevalent in all the treatments. This indicates a considerable mining of available K from the soil and suggest the need to adopt judicious fertilization.

Key words: Pearl millet-mustard cropping system, integrated nutrient management, long-term study, soil fertility

Pearl millet (*Pennisetum glaucum*) – mustard (*Brassica juncea*) cropping system got popularized during last several years under limited and assured irrigated condition, in alluvial soil region of northern Madhya Pradesh. Stagnation or decline in yield has been observed in many cropping systems in many parts of the country due to nutrient depletion, imbalances in use of plant nutrients and sub-optimal addition of organic and inorganic fertilizers to soil (Singh *et al.* 2009). There is an apprehension that the use of chemical fertilizers over the years might harm the soil fertility (Thakur *et al.* 2011). Long-term fertilizer experiments may provide precise information on the change in soil fertility and productivity and could be of great help in solving the soil fertility problems. Tiwari *et al.* (2002) are of the opinion that use of imbalanced nutrients (N or NP alone) through inorganic fertilizers without organic manure in continuous cropping can not sustain the desired level of crop production. Integration of inorganic with organic manures will not only sustain the crop production but will also be effective in improving soil health and enhancing the nutrient use efficiency (Verma *et al.* 2005). There is no information regarding the continuous cropping and nutrients used in conjunction with organic manure and biofertilizers, on pearl millet–mustard cropping system under Inceptisol of Indo-Gangetic plains of India. Hence, the present experiment was initiated in *kharif* 2003 and the results are presented in this paper in a condensed form.

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Materials and Methods

The present investigation is a part of an ongoining experiment with pearl millet-mustard cropping system in progress since *kharif* 2003 at the Research Farm of the Department of Soil Science and Agricultural Chemistry, Rajmata Vijayaraje Scindia Krishi Vishwa Vidyalaya, Gwalior, Madhya Pradesh (26°13′ N and 76°10′ E). Gwalior has a semi-arid and subtropical climate with a characteristic feature of dry summer and severe cold winter. In winter season *i.e.* October to March the temperature varies from 2 to 33 °C and the relative humidity varies from 52 to 92%.

Generally, dry and warm weather prevails during the months of March to June. The temperature in the month of May reaches as high as 46 °C. Monsoon season extends from first week of July to mid September. The total annual rainfall varies from 600 to 750 mm with the mean value of around 700 mm. The length of growing period of both the crops ranges from 200 to 210 days. The soil of the experimental field is alluvial belonging to hyperthermic family of Typic Ustochrept and sandy clay loam in texture having pH 7.55, EC 0.35 dS m^{-1}, organic carbon 3.65 g kg^{-1}; and available nitrogen (N), phosphorus (P) and potassium (K) were 170, 12 and 250 kg ha^{-1}, respectively. There were sixteen treatments *viz.*, T_1-control, T_2-50% NPK, T_3-75% NPK, T_4-100% NPK, T_5-150% NPK, T_6-100% NP, T_7-100% N, T_8-100%NPK-S, T_9-50% NPK + *Azotobacter,* T_{10}-75% NPK+ *Azotobacter,* T_{11}-100% NPK + *Azotobacter*, T_{12}-100% NPK +*Azotobacter* +PSB, T_{13}-50% NPK+ FYM, T_{14}-75% NPK+ FYM, T_{15}-100% NPK+ FYM, T_{16}-100% NPK+ FYM +*Azotobacter* + phosphate solubilizing bacteria (PSB). Each treatment was replicated thrice in a randomized block design. The recommended N, P and K doses, based on initial soil test, were 80 kg N, 40 kg P_2O_5 and 20 kg K_2O ha^{-1} for pearl millet and 100 kg N, 60 kg P_2O_5 and 40 kg K_2O ha^{-1} for mustard. The sources of N, P and K were urea, single super-phosphate and muriate of potash. In sulphur–free treatment, diammonium phosphate (DAP) was used instead of SSP as source of P. Farmyard manure (0.6% N, 0.21% P and 0.62% K) was incorporated treatment-wise @ 10 t ha^{-1} yr^{-1} (wet basis) in the soil 15 days before sowing of pearl millet crop during *kharif* season since 2003. Treatments T_9, T_{10} and T_{11} involved inoculation by *Azotobacter*, whereas, T_{12} and T_{16} had *Azotobacter* and PSB culture (@ 10 g kg^{-1} seed). Pearl millet and mustard varieties used were JBV-3 and Pusa bold, respectively, pearl millet in general was sown on the onset of monsoon (first to second week of July) as rainfed crop during *kharif* and mustard in the third to fourth week of October as irrigated crop during *rabi*. The crops were harvested at maturity and yield data were recorded after threshing. Soil samples from 0-15 cm depth were collected after harvest of mustard in the 10th cropping year (2012-13) and were analyzed for available N by alkaline permanganate method (Subbiah and Asija 1956), available P (Olsen *et al.* 1954) and available K (ammonium acetate extract). Grain and straw samples for P and K of both the crops were analyzed in 2:5 perchloric: nitric acid extract, P was determined colorimetrically by ammonium molybdate-vanadate reagent and K flame photometrically. Nitrogen was analyzed by micro-Kjeldahl system of Pelican. All observations were recorded for both the crops and soil properties were analyzed statistically.

Results and Discussion

Crop productivity

Data presented in table 1 regarding the treatment effect on yield of pearl millet and mustard clearly indicated that highest pooled grain yield of pearl millet (4.13 t ha^{-1}) and mustard (2.42 t ha^{-1}) were recorded in treatment receiving farm yard manure and biofertilizer with optimum level of NPK (100% NPK+ FYM+*Azotobacter*+PSB) and lowest yield of pearl millet and mustard were obtained in control plot. The results of 10 cycles of long-term fertilizer experiment showed that the application of 100% N alone had increased the yield by 27.6 and 25.2 per cent of pearl millet and mustard, respectively over control but the response exhibited a declining trend with time due to imbalanced use of nutrients. Supplementation of P with N (100% NP) enhanced the yields by 41.8 and 43.9 per cent in pearl millet and mustard, respectively. Application of K with NP further increased the yield significantly by 9.4 and 18.8 per cent. Yield reductions to the tune of 193 and 325 kg ha^{-1} were recorded in pearl millet and mustard, respectively in the plots in which sulphur (S) was not added (T_8) as compared to 100% NPK. Effect of S was more conspicuous in case of mustard, because of the fact that requirement of S is higher for oil seed crop (Bhat *et al.* 2007). It is thus evident from the result that for getting highest yield response application of sulphur is essential besides other major nutrients.

Incremental addition of NPK @ 50, 75, 100 and 150% resulted in 43.3, 56.0, 78.8 and 86.8 per cent increase in yield of pearl millet and 55.2, 72.3, 87.9 and 104.5% increase of mustard, respectively over control (Table 1). Super optimal dose of NPK (150%) also increased yield over optimal dose (100% NPK), however, increase in yield of mustard was more than that in pearl millet. These findings clearly indicate that nutrient requirement, in terms of balanced fertilization, is higher for mustard crop.

It is interesting to note that seed treatment of pearl millet and mustard (T_9 and T_{10}) with *Azotobacter* produced beneficial effect on yield in comparison to NPK alone (T_2 and T_3). It appears from the results that biofertilizers also play useful role for these crops. In continuous cropping, the application of organic manure (10 t FYM ha^{-1} yr^{-1}) along with NPK dose

Table 1. Effect of nutrient management options on yield of pearl millet and mustard over 10 years (Pooled for 2003-2013)

Treatments	Pooled average grain yield (t ha^{-1})		Increase over control (%)	
	Pearl millet	Mustard	Pearl millet	Mustard
T_1 : Control	2.04	1.05	-	-
T_2 : 50% NPK	2.95	1.64	43.3	55.2
T_3 : 75% NPK	3.21	1.82	56.0	72.3
T_4 : 100% NPK	3.68	1.98	78.8	87.9
T_5 : 150% NPK	3.84	2.16	86.8	104.5
T_6 : 100% NP	3.49	1.78	69.4	69.1
T_7 : 100% N	2.63	1.32	27.6	25.2
T_8 : 100% NPK-S	3.49	1.66	69.4	57.0
T_9 : 50% NPK+*Azotobacter*	3.13	1.73	52.0	64.0
T_{10} : 75% NPK+*Azotobacter*	3.36	1.87	63.2	77.1
T_{11} : 100% NPK+*Azotobacter*	3.69	2.09	79.2	97.9
T_{12} : 100% NPK+*Azotobacter*+PSB	3.81	2.19	85.3	107.8
T_{13} : 50% NPK+FYM	3.26	1.88	58.4	78.3
T_{14} : 75% NPK+FYM	3.48	2.08	69.2	97.5
T_{15} : 100% NPK+FYM	3.85	2.31	87.1	119.4
T_{16} :100% NPK+FYM+*Azotobacter*+PSB	4.13	2.43	100.9	130.2
CD (P= 0.05)	0.16	0.15	-	-

(50, 75 and 100% NPK) was found to be beneficial in enhancing the crop productivity over NPK, as on supplementing the inorganic with organic and biofertilizer (T_{16}) further increase in yield was recorded by 0.29 and 0.27 t ha^{-1} over 150% NPK of pearl millet and mustard, respectively. The increase in yield might have resulted from the growth regulating substances produced by *Azotobacter* besides fixation of additional N from atmosphere, thereby increasing the N availability in the soil. The PSB also help in solubilizing the fixed P. It appears from the results that integrated use of optimal dose of inorganic, organic manure and biofertilizer treatment (T_{16}) is superior to super optimal dose of inorganic alone (T_5). The beneficial effect of combined use of organic manure and inorganic and biofertilizers in terms of nutrient availability increased through enhanced microbial activity, conversion from unavailable forms and also due to improved physical, chemical and biochemical conditions. These results are in conformity with the findings of Bhattacharyya *et al*. (2008). Thus, the balanced use of nutrients preferably in combination with organic manure is necessary for sustaining productivity of crops. Mishra *et al.* (2008) also reported beneficial effect of conjoint application of inorganic and organic manure in maize-wheat cropping system in Alfisol.

Nutrient balance in soil

Data presented on inputs (nutrients applied) and output (nutrient uptake) indicate negative balance of N and P in treatments where adequate nutrients were not added (T_1, T_2, T_3 and T_9). Besides these treatments, negative balance of P was also recorded in T_7 (Table 2), whereas negative balance of K was found in all the sixteen treatments of pearl millet–mustard cropping system under the best management practices. It appears from the results that nutrients added in amounts less than the optimum level are not capable of meeting the nutrient requirement of the crops. It is also evident that much more attention is required to be paid for K to maintain K status of soil and to prevent K mining (Mahapatra *et al*. 2007).

Soil fertility

Annual addition of 10 t FYM to the pearl millet helped in maintenance of available N and P, and maximum available N and P status was observed in 100% NPK+FYM+*Azotobacter*+PSB (Table 3). Although marginal increase in the status of P was recorded in the treatments receiving optimum and super-optimal levels of NPK, there was negative balance of P in control, 100% N and 50% and 75% NPK applied singly or in combination with *Azotobacter*. The negative P balance is obviously due to absence or inadequate addition of P, whereas positive P balance may be attributed to the addition of P in excess of its uptake by crops (Dwivedi *et al.* 2007). Higher build-up of P recorded in treatments receiving PSB clearly indicates towards the beneficial and solubilizing effect on fixed P by PSB.

A perusal of data revealed a declining trend (37 to 101 kg ha^{-1}) as compared to the initial level (250 kg ha^{-1}) of available K which indicates a considerable

Table 2. Nutrient balance (kg ha^{-1} yr^{-1}) in soil under pearl millet–mustard cropping system as affected by different treatments

Treatments	Nutrient additions through manure and fertilizers (kg ha^{-1} yr^{-1})			Nutrient removal by pearl millet mustard (kg ha^{-1} yr^{-1})			Nutrient balance (kg ha^{-1} yr^{-1})		
	N	P	K	N	P	K	N	P	K
T_1 Control	0	0	0	103.3	21.1	120.4	-103.3	-21.1	-120.4
T_2 50% NPK	90	21.8	30.0	137.6	31.0	170.2	-47.6	-9.23	-140.2
T_3 75% of NPK	135	32.7	45.0	173.1	39.6	209.9	-38.1	-6.89	-164.9
T_4 100% of NPK	180	43.7	60.0	211.5	47.3	243.0	-31.5	-3.68	-183.0
T_5 150% of NPK	270	65.5	75.0	232.9	52.0	276.4	+37.0	+13.4	-201.4
T_6 100% NP-K	180	43.7	0.0	195.6	41.4	206.9	-15.6	+2.29	-206.9
T_7 100% N	180	0.0	0.0	156.5	29.3	159.8	+23.4	-29.3	-159.8
T_8 100% NPK-S	180	43.7	50.0	190.4	43.3	225.5	+10.4	+0.32	-175.5
T_9 50% NPK+*Azotobacter*	90	21.8	25.0	169.6	35.0	190.1	-79.6	-13.24	-165.1
T_{10} 75% NPK+*Azotobacter*	135	32.7	45.0	193.6	43.8	223.9	-58.6	-11.06	-186.4
T_{11} 100% NPK+*Azotobacter*	180	43.7	60.0	223.8	50.6	265.4	-43.8	-6.90	-205.4
T_{12} 100% NPK+*Azotobacter*+PSB	180	43.7	60.0	246.4	56.4	277.1	-66.3	-12.7	-217.1
T_{13} 50% NPK+FYM*	150	42.8	92.5	194.9	39.3	207.2	-448	+3.46	-154.7
T_{14} 75% NPK+FYM	195	53.7	107.5	226.2	48.8	249.6	-31.2	+4.96	-142.1
T_{15} 100% NPK+FYM	240	64.7	122.5	263.5	56.2	286.6	-23.5	+8.46	-164.1
T_{16} 100%NPK+FYM+ *Azotobacter* +PSB	240	64.7	122.5	286.7	64.3	305.3	-46.7	+0.33	-182.8
CD (P= 0.05)	-	-	-	17.2	4.3	18.5	-	-	-

Table 3. Available nutrient status in soil under pearl millet–mustard cropping system at harvest of mustard - 2013

Treatments	Available nutrient content after harvest of mustard 2013 (kg ha^{-1})			Apparent nutrient changes as compared to their initial values (kg ha^{-1})			Increase/decrease in nutrient content of soil (kg ha^{-1} yr^{-1})		
	N	P	K	N	P	K	N	P	K
Initial status (2003)	170	12	250	-	-	-	-	-	-
T_1 Control	112	3.3	149	-58	-8.7	-101	-5.8	-0.9	-10.1
T_2 50% NPK	140	9.7	176	-30	-2.3	-74	-3.0	-0.2	-7.4
T_3 75% of NPK	166	10.8	185	-4.0	-1.2	-65	-0.4	-0.1	-6.5
T_4 100% of NPK	190	14.4	188	+20	+2.4	-62	2.0	0.2	-6.2
T_5 150% of NPK	208	20.7	195	+38	+8.7	-55	3.8	0.9	-5.5
T_6 100% NP-K	182	12.2	153	+12	+0.2	-97	1.2	0.0	-9.7
T_7 100% N	178	4.0	156	+8	-8.0	-94	0.8	-0.8	-9.4
T_8 100% NPK-S	190	13.1	194	+20	+1.1	-56	2.0	0.1	-5.6
T_9 50% NPK+*Azotobacter*	166	10.3	190	-4	-1.7	-60	-0.4	-0.2	-6.0
T_{10} 75% NPK+*Azotobacter*	186	12.2	199	+16	+0.2	-51	1.6	0.0	-5.1
T_{11} 100% NPK+*Azotobacter*	199	15.3	202	+29	+3.3	-48	2.9	0.3	-4.8
T_{12} 100% NPK+*Azotobacter*+PSB	206	27.1	206	+36	+15.1	-44	3.6	1.5	-4.4
T_{13} 50% NPK+FYM	176	13.2	191	+6	+1.2	-59	0.6	0.1	-5.9
T_{14} 75% NPK+FYM	211	17.6	199	+41	+5.6	-51	4.1	0.6	-5.1
T_{15} 100% NPK+FYM	234	24.9	212	+64	+12.9	-38	6.4	1.3	-3.8
T_{16} 100% NPK+FYM+*Azotobacter* + PSB	253	32.3	213	+83	+20.3	-37	8.3	2.0	-3.7
CD (P= 0.05)	4.9	1.5	8.2	-	-	-	-	-	-

mining of available K, after 10 years of intensive cropping (Table 3). Maximum decline (-101 kg ha^{-1}) was observed in control followed by 100% NP. The magnitude of decline decreased with increasing levels of NPK application. Among the inorganic fertilizers, continuous application of N alone or NP adversely affected the available K content of the soil, which may be attributed to no application of potassic fertilizer, which also resulted in nutrient imbalance in the soil. Highest available K status (212 kg ha^{-1}) of soil was found in the treatment 100% NPK+FYM followed by 150% NPK (195 kg ha^{-1}). Prasad and

Mathur (1997) opined that organic matter might have caused reduction in K fixation and consequentially increased available K content due to interaction of organic matter with clay, besides the direct addition to the available K pools of soil. From the results it is evident that the present K recommendations are not sufficient and need revision; otherwise there is a possibility of abrupt decline in production in near future.

It is concluded that over ten years of pearl millet–mustard cropping system, the treatment receiving organic manure along with optimal dose of chemical fertilizer in combination with *Azotobacter* and PSB provided highest yield of both crops and improved soil fertility. These findings showed that the integration of FYM @ 10 t ha^{-1} yr^{-1} and biofertilizer with 100% NPK sustained higher productivity and uptake of nutrients by the crops. It not only restored the original fertility status of soil but also improved nutrient status at harvest which may be beneficial for the sustaining the productivity of the system.

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