International Journal of Chemical Studies

P-ISSN: 2349–8528
E-ISSN: 2321–4902
IJCS 2017; 5(5): 1237-1243

Received: 21-07-2017
Accepted: 23-08-2017

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Influence of integrated nutrient management on soil fertility and properties of sandy clay loam and relationship with productivity of pearlmillet (*Pennisetum glaucum*) – mustard (*Brassica juncea*) cropping sequence

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Abstract
The field study was conducted from *kharif* season of 2010 to *rabi* 2012 of pearl millet (*Pennisetum glaucum)* – mustard (*Brassica juncea*) cropping sequence to study the effect of integrated nutrient management on fertility status, soil physico-chemical properties and productivity of sandy clay loam. The experiment was parts of long-term fertility experiment started from *kharif* season 1997 at Gwalior, Madhya Pradesh on permanent plots comprised 16 treatments with three replications in randomised block design consist unfertilized control, imbalanced fertility treatments and optimal to sub optimal dose of chemical fertilizer alone treatments or in combinations with farmyard manure (@10t/ha/year) or bio fertilizers. The soil samples were collect from all treatments at 0-15 and 15-30 cm depth to identify the fertility status and soil physico-chemical properties. 100% NPK +FYM @10t/ha/year + Azotobacter +PSB recorded significantly highest amount of organic carbon (5.34 to 4.47 g/kg), available N (253 to 195 kg/ha), P (32.3 to 22.3 kg/ha) and K (224 to 213 kg/ha), sustain soil pH (7.50 to 7.52) and EC (0.24 to 0.18 dS/m) from surface to subsurface soil, respectively; reduced % $CaCO_3$ (1.00%), improve the soil BD (1.25 Mg/m^3) percent porosity (53%), infiltration rate (0.94 mm/hr) and MWHC (0.51m^3/m^3) and enhance the productivity as seed (4.0 and 2.1 t/ha) and straw (8.8 and 7.0 t/ha) yield of pearl millet and mustard, respectively over the other fertility treatments and control. Application of 150% NPK significantly produced the higher yield; improve available N-P-K, OC and physico-chemical properties of soil over 100%NPK alone, imbalanced fertility treatments (100%N, 100%NP and 100%NPK-S), sub-optimal dose fertility treatments and control but performance was poor over integrated treatments having combination of optimal dose of chemical fertilizer with farmyard manure or bio fertilizers. Highly significant positive correlation of total productivity was observed with available N- P-K and MWHC and moderately positive significant correlation with OC and percent porosity; whereas moderately negative significant correlation observed with BD and %$CaCO_3$.

Keywords: crop productivity, fertility status, integrated nutrient management, soil physico-chemical properties.

Introduction
Pearl millet-mustard is the most prevalent cropping sequence adopted in substantial area of Madhya Pradesh, India. Pearl millet [*Pennisetum glaucum* (L.) R. Br. Emend. Stutz] – mustard [*Brassica juncea* (L.) Czern. & Coss.] is most prominent and popular cropping system under limited irrigation conditions to meet the national shortfall of food grain and edible oil and having contribution of this cropping system to total food grain and oilseed production is considerably large, being 3.5% of pearl millet with 7.7 million tonnes of production (Parihar *et al*. 2013) [11]. Pearl millet having fourth position under cereals and widely grown because of having tolerance to drought, high temperature and low soil fertility and present it occupying 8.7 million ha area with a total production of 10.1 million tonnes (Economic Survey 2011-12) [4]. Rapeseed – mustard group of crops is the third largest oilseed crop in India after soybean and groundnut and occupying 5.9 million ha area with production of 6.8 million tonnes (Economic Survey 2011-12) [4]. Long-term fertility experiments gave the valuable information on effect of continuous application of different levels of fertilizers, alone and in combination with and without organic manure under intensive cropping on soil fertility and corp

productivity. The decline in soil fertility due to deficiency of nutrients other than the applied in the form of chemical fertilizers and the decline in organic carbon are the matter of nutrient imbalance which has been recognized as one of the most important factors that limit crop yield. The mineral fertilizer application has reached such high levels that many ill side effects are appearing, such as adverse effects on soil properties, over-exploitation of natural resources, ground water pollution, etc. Continuous application of nitrogenous fertilizers has depleted soil organic matter, resulting in inherent losses of native soil N, available P and available K and lower down the production (Walia *et al*. 2010) [22]. Addition of organic manures along with chemical fertilizers is known to stimulate organic matter turnover which affect the inter conversion of different fractions of the nutrients and modify their availability in the soil (Patel 2009) [13]. Prasad *et al.* (1996) [15] reported that integrated use of organic manure with chemical fertilizers resulted in buildup of available nutrients in soil much more effectively than that of chemical fertilizer alone. Hence, it is desirable to encourage integrated nutrient management system by reverting to the use of farmyard manure (FYM) in combination with chemical fertilizers for maintaining sustainability of agriculture. The physico- chemical properties of the soil improved significantly by addition of organic manure and that there was very little change due to inorganic fertilizers. It is apparent that there is a need to generate more information on integrated nutrient recommendations for cropping system for sustains crop production through increased soil productivity in long term experiments (Dhone and Bakare, 2008) [3]. The continuous supply of organic manure in combination with chemical fertilizer and bio fertilizers store the organic carbon of the soil and also supplements the nutrient pool of the soil and maintain soil physico-chemical properties. The precise information on the long-term effect of integrated nutrient management on soil fertility in pearl millet-mustard cropping system is lacking. In view of these considerations, the present investigation was undertaken to assess the long-term effect of integrated nutrient management with or without organic manure and bio fertilizers on fertility status, physico-chemical properties of soil and their relationship with productivity of pearl millet-mustard cropping sequence.

Materials and methods

The present investigation is a part of an ongoing long-term fertility experiment with pearlmillet-mustard cropping sequence which was initiated during year 1997 on research farm, Rajmata Vijayaraje Sciendia Krishi Vishwa Vidyalaya, Gwalior, Madhya Pradesh in permanent plots located at latitude of26^0 13’N and longitude 76^0 10’E with an altitude 197 meters. The climate of experimental site is semi-arid and subtropical with extreme weather conditions having hot and dry summer and cold winter, where maximum temperature goes up to 45^0C during summer and minimum as low as 2.8^0C in winter. The mean annual rainfall of area is 700-800 mm. The soil of the experimental field was alluvial, sandy clay loam in texture and classified as Typic Ustochrepts at sub group level. The experimental field was cropped for Jowar fodder-mustard sequence from initial period of experiment (1997) up to *rabi*period 2002-2003. From *kharif* season of 2003-2004 pearlmillet- mustard cropping sequence was started without any changes under all fertility treatments and experimental plots. The experiment was laid out with randomize block design having three replications comprising of 16 treatments, *viz* Control (no fertilizer/manure), 50%NPK, 75%NPK, 100%NPK, 150%NPK, 100%NP, 100%N, 100%NPK-S (sulphur free), 50%NPK+*Azotobactor* (@10g/kg seed), 75%NPK+*Azotobactor*, 100%NPK+ *Azotobactor*, 100%NPK+ *Azotobactor* + Phosphate Solubilising Bactria (PSB), 50%NPK+ Farmyard Manure (FYM) @10 t/ha/year, 75%NPK+ FYM @10t/ha/year, 100%NPK+ FYM @10t/ha/year, 100%NPK+ FYM @10t/ha/year+ *Azotobactor* + PSB, respectively. The recommended dose for pearl millet and mustard were 80: 40: 20 and 100:60:40 N, P_2O_5 and K_2O Kg/ha. Half of the nitrogen was applied in the form of urea as a basal dose and remaining was top dressed after 1st irrigation at 30 DAS under both crops. Full dose of phosphorus and potash applied as single supper phosphate and murate of potash at the time of sowing. In treatment 100%NPK-S, P was added as DAP to make it sulphur free treatment. As per treatment farm yard manure (FYM) was applied every year @ 10 t/ha/year before sowing of pearl millet. In inoculation treatment seed were treated with *Azotobactor* and Phosphate Solubilising Bactria both @10 g/Kg seed. Pearl millet ‘JBV-3’ was sown (seed rate 5kg/ha) during the middle of July and harvested in second week of October and mustard ‘Pusa bold’ was sown (seed rate 5kg/ha) during first to second week of November and harvested at the end of April each year.

The grain and straw yield of each crop were recorded and plot wise soil sample were collected from 0-15and 15-30 cm of soil depths at the initial period of study in *kharif*2010-11, before sowing of pearl millet (1st crop) and after harvest of mustard *rabi*2011-12 (4th crop) to study the impact of various fertility treatment on soil properties. At the beginning of experiment (1997) under Jowar fodder-mustard sequence soil having pH (7.78) neutral to slightly alkaline, low in EC (0.13 dS/m), OC (3.6 g/kg) and available P (7.2 Kg/ha) and medium available N (145 Kg/ha), and K (197 Kg/ha). The cropping sequence is change to pearlmillet – mustard from 2003 (*kharif*) recorded soil pH 7.77, EC 0.15 dS/m, OC 3.4 g/kgsoil and available N 139 Kg/ha, P 6.5 Kg/ha and K 185 Kg/ha.

Soil samples were analyzed for *pH* (1:2.5 soil: water suspension, Jackson, 1967[7]), electrical conductivity by using ELICO conductivity bridge (Richards, 1954) [15]. Organic carbon by rapid titration method (Walkley and Black 1934) [23], available nitrogen by alkaline permanganate method (Subbaiah and Asija, 1956) [20], available phosphorous (Olsen *et al*.1954) [10] and available potassium by ammonium acetate extraction method (Jackson, 1967) [7]. Soil bulk density (Mg m^{-3}) was determined by using core sampler by known volume at field moisture and infiltration was measured with a double-ring infiltrometer at the end of study by Richards (1954) [16], maximum water holding capacity (MWHC) of soil was determined by Keen-Raczkowski brass cup method (Piper, 1966) [14].

Results and discussion

Organic carbon

The soil organic carbon under different fertility treatments of integrated nutrient management showed variations during the period of study and all fertility treatments showed build-up of soil organic carbon over control and initial status (year 1997, 3.60 g/kg) at surface soil. The significantly highest organic carbon were recorded at surface (5.22 to 5.34 and 4.75 to 4.83 g/kg) and sub-surface (4.35 to 4.47 and 3.90 to 4.00 g/kg) from initial to finial period of study (Table 1), respectively in treatments receiving 100% NPK + FYM @10t/ha/year + *Azotobactor* + PSB and 100%NPK+FYM@10t/ha/year and showed percent build-up of organic carbon by 23% and 11%

for surface soil over the super optimal dose 150 %NPK treatment at the end of study. The fertility treatments receiving farmyard manure in combination with different levels of chemical fertilizers (50% NPK+FYM@10/t/ha/year, 75% NPK+FYM@10/t/ha/year, 100% NPK +FYM @10/t/ ha/ year and 100% NPK+FYM@10/t/ha/year + Azotobactor +PSB) showed maximum build-up of organic carbon over the same level of chemical fertilizer alone (50%NPK, 75%NPK and 100%NPK) or in combination with biofertilizers treatments (50%NPK +Azotobactor, 75% NPK +Azotobactor, 100% NPK + Azotobactor and 100% NPK + Azotobactor + PSB). The increasein organic carbon content due to use of chemical fertilizer, direct incorporation of organic matter through FYM can be attributed to higher contribution of biomass to the soil in the form of better root growth, crop stubbles biomass and residues. Similar findings were recorded by Gathala *et al.* (2007) [5] and Walia *et al*. (2010) [22] under long-term fertility experiment. The application of 30 kg/ha sulphur along with 100% NPK (4.09 g/kg) also recorded increased in organic carbon compared to 100%NPK-S (S-free) (3.91g/kg) at surface soil. This was probably due to higher biomass production with balanced supply of NPK and S. The imbalanced fertility treatments 100%N (3.87 to 3.62 and 3.14 to 3.05 g/kg) alone and 100% NP (3.82 to 3.57 and 3.27 to 3.16) and showed regular build-up of organic carbon over control (3.38 to 3.13 and 2.70 to 2.50 g/kg) for surface and subsurface soil, respectively but performance was poor over optimal dose of fertility treatments and initial period of study.

Fertility status

The available major nutrients were substantially influenced by different nutrient management treatments (Table 1). Initially (year1997) the soil had 145 Kg/ha N, 7.2 Kg/ha P_2O_5 and 197 kg/ha K_2O. The respective soil available nutrients reduced to 129, 4.9 and 153 to 112, 3.3 and 138 for surface and 118, 4.0 and 159 to 110, 3.0 and 149 kg/ha for subsurface soil of control plot from initial to final period (year 2010-2012) of present study. Availability of these nutrients increased with increased in levels of fertilizers application from suboptimal dose to optimal and supper optimal dose of fertility.

The long term fertilization with100%NPK+ FYM @10/t/ha/year + *Azotobactor* +PSB (253 and 195 kg/ha) and 100% NPK+ FYM @10/t/ha/year (234 and 186 kg/ha) showed significant increase in available N for surface and subsurface at the end of experiment over 100% NPK (193 and 171 kg/ha) and super-optimal dose 150% NPK (208 and 182 kg/ha) alone treatment. Such increase in available nitrogen is due to mineralization of FYM. Singh *et al.* (2009) [18] reported that available nitrogen content in soil was higher with the use of recommended dose of fertilizer in combinations with organic manure which might have helped in multiplication of soil microbes, ultimately conversion of organically bound N to mineral form (Tolanur and Badnur 2003) [20]. The increased amount of available nitrogen in treatments receiving 100% NPK+ Azotobactor (199 and 170 kg/ha), 100% NPK+ Azotobactor + PSB (206 and 167 kg/ha) over 100%NPK, was due to inoculation of seed by *Azotobactor*, which might have helped in increasing the supply of nitrogen through biologically fixing the atmospheric nitrogen (Hegde1998)[6].

The availability of P increased to the extent of 48 % and 33% in 100% NPK over 50% NPK and 75%NPK and by 44 % was found in 150%NPK over 100%NPK treated plot. The maximum build-up of P recorded in treatment 100% NPK + FYM @10 t/ha/year +*Azotobactor* +PSB (8 and 4 kg/ha), 100%NPK+ *Azotobactor* + PSB (7 and 4 kg/ha) and 100% NPK+FYM@10 t/ha/year (5 and 5 kg/ha) for surface and subsurface, respectively during the period of study which may be attributed to the solubilisation of native P in the soil by organic and inorganic acids released from the decomposition of FYM and by microbiological action on insoluble-P compounds, accompanied by acidification of the medium which enhanced the availability of P to the plant (Mahdi *et al*., 2010) [9].The available P status decreased under treatment receiving 100%N (4 kg/ha) alone over its initial status (5.4kg/ha)and 100% NP (12.2 kg ha^{-1}) at surface soil due to the removal of phosphorus by crop under long-term cropping, similar trend on available phosphorus was reported by Parmer and Sharma (2002) [12].

The available K status of soil was recorded higher for surface soil of treatment 100%NPK+FYM@10t/ha/year +*Azotobactor* +PSB (224 and 213 kg/ha) fallowed by 100%NPK+ FYM@10 t/ha/year (214 and 212 kg/ha) for surface and subsurface soil at the end of study over the other fertility treatments and control plot. Both treatment showed percent build by up of 14.3 to 12.3 and 5.8 to 6.7% for surface and sub-surface soil respectively over the 100%NPKand 150%NPK treated plots at the end of study. Continuous cropping without addition of external source of K and imbalanced supply of nutrients (N and NP) reduced the availability of K at the end of study (2012) over the initial status (1997) of soil and start of present study (2010) period. This might be due to continuous omission of K and or imbalanced fertilization in crop nutrition caused mining of its native pools that also caused reduction in crop yields (Subehia *et al.*2005) [20].

Table 1: Effect of integrated nutrient management on soil organic carbon and fertility status of soil under pearlmillet-mustard cropping sequence.

	Initial (before sowing of kharifpearlmillet 2010)								Final (After harvest of rabbi mustard 2012)							
	OC	N	P_2O_5	K_2O	OC	N	P_2O_5	K_2O	OC	N	P_2O_5	K_2O	OC	N	P_2O_5	K_2O
	(g/kg)	………Kg/ha…..			(g/kg)	………Kg/ha…..			(g/kg)	……Kg/ha…..			(g/kg)	…….Kg/ha..…..		
Treatments /Depth (cm)	……….. (0 - 15)…………				………. (15 - 30)…………				……….. (0 - 15)…………				………. (15 - 30)…………			
T_1-CONTROL	3.38	129	4.9	153	2.70	118	4.0	159	3.13	112	3.3	138	2.50	110	3.0	149
T_2-50%NPK	3.77	153	9.9	169	3.01	143	6.3	183	3.62	140	9.7	159	2.90	139	5.8	176
T_3-75%NPK	3.92	171	10.3	183	3.31	153	8.5	190	3.72	166	10.8	176	3.22	148	7.9	185
T_4-100%NPK	4.09	188	12.5	194	3.47	170	9.3	186	4.05	193	14.4	192	3.44	171	10.5	188
T_5-150%NPK	4.22	195	16.9	205	3.95	177	10.1	190	4.33	208	20.7	211	4.03	182	12.9	195
T_6-100%NP	3.82	183	11.9	166	3.27	163	8.5	163	3.57	182	12.2	154	3.16	163	7.5	153
T_7-100%N	3.87	178	5.4	164	3.14	155	2.7	166	3.62	178	4.0	150	3.05	153	2.0	156
T_8-100%NPK-S	3.91	187	12.2	192	3.29	168	8.0	196	3.91	190	13.1	189	3.29	170	8.1	194
T_9-50%NPK+AZO	3.93	165	10.3	182	3.38	147	6.4	196	3.85	166	10.3	173	3.35	147	6.0	190
T_{10}-75%NPK+AZO	4.07	185	11.9	199	3.40	154	8.1	199	4.05	186	12.2	195	3.40	154	7.9	199
T_{11}-100%NPK+AZO	4.25	190	13.8	203	3.55	163	10.8	201	4.37	199	15.3	205	3.65	170	14.2	202

T_{12}-100%NPK+AZO+PSB	4.38	195	20.1	211	3.72	159	15.8	203	4.51	206	27.1	216	3.83	167	20.1	206
T_{13}-50%NPK+FYM	4.05	176	12.8	200	3.53	151	9.6	193	3.94	176	13.2	193	3.45	152	9.7	191
T_{14}-75%NPK+FYM	4.60	204	16.2	202	3.72	174	14.1	199	4.58	211	17.7	201	3.72	181	15.5	199
T_{15}-100%NPK+FYM	4.75	224	19.8	210	3.90	178	16.1	210	4.83	234	24.9	214	4.00	186	20.8	212
T_{16}-100%NPK+FYM+AZO+PSB	5.22	238	24.8	218	4.35	184	18.4	210	5.34	253	32.3	224	4.47	195	22.3	213
SEm±	0.05	1.4	0.7	2.5	0.05	2.0	0.4	3.8	0.6	4.1	0.6	1.8	0.07	2.9	0.6	3.4
CD(P=0.05)	0.14	4.1	2.0	7.1	0.15	5.9	1.3	11.1	0.18	11.8	1.8	5.2	0.20	8.5	1.6	7.9

Note: AZO: Azotobacter, PSB phosphate solubilizing bacteria, FYM: farmyard manure

Physico-chemical properties of soil

The changes in physical and chemical properties of soil due to integrated nutrient management in pearl millet-mustard cropping sequence are presented in table 2 and 3. The bulk density and porosity of soil during 2 years of study period (2010-12) do not showed the significant changes over a short period of study but changes may be due to long-term fertilizer application with respect to treatments. Treatments receiving optimal dose of chemical fertilizer alone or in combination with farmyard manure or bio fertilizers showed considerably low valueof bulk density and maximum porosity over the suboptimal dose of fertility treatments. The annual application of farmyard manure in combination with optimal dose of chemicals showed significant changes in 100%NPK + FYM @10t/ha/year + *Azotobacter* +PSB (1.25 Mg/m^{3}and 53.0%), 100% NPK + FYM @10t/ha/year (1.29 Mg/m^3 and 51.8%) over other fertility treatments, imbalanced fertility treatments and control (1.49Mg/m^3 and 44.5%) plot.

The highest value of infiltration rate and maximum water holding capacity (0-15 and 15-30 cm) was recorded as 0.98and 51 to 47 (100% NPK + FYM @10t/ha/year + *Azotobacter* + PSB), followed by 0.94 and 47 to 45 (100%NPK+FYM@10t/ha/year), 0.92 and 45 to 39 (75 %NPK+FYM@10t/ha/year) and 0.88mm/hr and 42 to 41 m^3/m^3 (50%NPK+FYM@10t/ha/year) were recorded in farmyard treated plot in combination with various levels of chemical fertilizers over the same level of chemical fertilizer alone treated plots and unfertilized control (table 2).The continuous addition of organic manures crop by crop increased not only crop biomass but also increased the organic matter level of soil, and was attributed to their higher pore space, low bulk density and favourable soil structure which resulted in an increased water holding capacity of the soil (Bhaskaran, 2009) [2]. Whereas lowest infiltration rate was recorded for imbalanced fertility treatments 100%N (0.63 mm/hr) and 100%NP (0.66 mm/hr) and showed poor water holding capacity (27 to 30 and 36 to 40 m^3/m^3) over the other balanced fertility treatments.

The initial status of soil reaction and electrical conductivity was recorded in year 1997 was 7.77 and 0.15 dS/m. After the 14th cycle of pearl millet-mustard cropping sequence pH of surface and subsurface soil showed variations due to different fertility treatments and ranged between 7.54 to 7.85 and 7.50 to 7.89 whereas EC was found 0.11to 0.23 and 0.11 to 0.24 dS/m during the present period of study (2010-12) (table 3).The lowest soil pH recorded for surface soil (0-15cm) was 7.50 under 100% NPK along with FYM @10 t/ha/year +*Azotobacter* + PSB. The pH showed only marginal declinetrend on surfaceby 7.68 to 7.65, 7.65 to 7.64 and 7.62 to 7.58 under treatments receiving 100% NPK + *Azotobactor*, 100% NPK +*Azotobactor* + PSB, 100% NPK + FYM @10 t/ha/year respectivelyover initial value. Decrease in pH may be attributed to balance use of fertilizer with FYM and seed inoculants (*Azotobactor*, PSB), which released organic acids during decomposition of manures resulting decline in soil pH. The increase in pH at subsurface (15 - 30 cm) attributes to continuous application of imbalance use of nutrient (100%N alone 7.85 to 7.89) which decline soil health and increased soil pH. Electrical conductivity (EC) was not much affected by different fertility treatments over the experimental period. The highest EC (0.24 dS/m) found under treatment 100%NPK + FYM @10 t/ha/year + *Azotobactor* + PSB. There was marginal increase in EC on surface under 150% NPK (0.19 to 0.21dS/m) and FYM in combination with chemical fertilizer (0.17, 0.19 and 0.21 dS/m) as compare to other treatments, which received chemical fertilizer alone and sub optimal dose treatments. These increases in EC obviously due to decomposition of organic matter, these results corroborate the findings of Babu *et al*. (2007) [1].

The soil was slight to moderately calcareous and having lower calcium carbonate content at surface soil (0-15 cm) compared to subsurface with few exceptions. The highest value 1.83 (15-30cm) of percent $CaCO_3$was recorded under treatment 150%NPK fallowed by 1.66% under most of fertility treatments under surface or subsurface soil having sub optimal to optimal dose and imbalanced fertility treatments and control. The treatments receiving farmyard manure @10t/ha/year in combination with optimal dose of chemical fertilizers showed lower value 1.00% (0-15cm) of $CaCO_3$however, the changes during two years of study period were not identical with respect to treatments. Slight increase in value under most of treatments might be due to increase in atmospheric temperature during summer which may be responsible for the formation of pedogenic calcium carbonate. These findings are in line with Sahrawat (2003) [17].

Table 2: Influence of integrated nutrient management on soil physical properties

Soil properties	**BD (Mg/m^3)**		**Porosity (%)**		**Infiltration**	**MWHC (m^3/m^3)**			
	(2010)	**(2012)**	**(2010)**	**(2012)**	**rate (mm/hr)**	**(2010)**		**(2012)**	
Treatments/depth (cm)	**…………………...0-15………………...**					**0-15**	**15-30**	**0-15**	**15-30**
T_1-CONTROL	1.47	1.48	44.9	44.5	0.71	0.26	0.28	0.24	0.28
T_2-50%NPK	1.43	1.43	46.3	46.3	0.70	0.38	0.37	0.36	0.37
T_3-75%NPK	1.42	1.42	46.8	46.8	0.71	0.37	0.36	0.34	0.36
T_4-100%NPK	1.39	1.40	48.0	47.7	0.75	0.38	0.36	0.40	0.36
T_5-150%NPK	1.38	1.39	48.3	47.9	0.87	0.40	0.42	0.43	0.45
T_6-100%NP	1.42	1.44	46.9	46.1	0.66	0.36	0.40	0.36	0.40
T_7-100%N	1.47	1.49	44.8	44.3	0.63	0.27	0.31	0.27	0.30
T_8-100%NPK-S	1.41	1.41	47.0	47.0	0.78	0.38	0.40	0.36	0.40
T_9-50%NPK+AZO	1.41	1.41	47.1	47.1	0.72	0.40	0.38	0.37	0.38

T_{10}-75%NPK+AZO	1.39	1.39	47.9	47.9	0.74	0.40	0.37	0.40	0.37
T_{11}-100%NPK+AZO	1.36	1.35	49.0	49.6	0.85	0.39	0.41	0.43	0.44
T_{12}-100%NPK+AZO+PSB	1.34	1.32	49.9	50.6	0.86	0.40	0.37	0.48	0.40
T_{13}-50%NPK+FYM	1.36	1.35	49.2	49.3	0.86	0.39	0.41	0.42	0.41
T_{14}-75%NPK+FYM	1.33	1.32	50.2	50.6	0.88	0.42	0.37	0.45	0.39
T_{15}-100%NPK+FYM	1.30	1.29	51.3	51.8	0.92	0.41	0.42	0.47	0.45
T_{16}-100%NPK+FYM+AZO+PSB	1.27	1.25	52.4	53.0	0.94	0.43	0.42	0.51	0.47
SEm±	0.02	0.01	0.58	0.33	0.68	0.01	0.00	0.03	0.01
CD(P=0.05)	0.05	0.04	1.67	0.95	1.97	0.02	0.06	0.10	0.04

Note: BD: soil bulk density, MWHC: maximum water holding capacity

Table 3: Influence of integrated nutrient management on soil chemical properties

Soil properties	**pH**				**EC (dS/m)**				**$CaCO_3$ (%)**			
	2010		**2012**		**2010**		**2012**		**2010**		**2012**	
Treatments/depth (cm)	**0-15**	**15-30**	**0-15**	**15-30**	**0-15**	**15-30**	**0-15**	**15-30**	**0-15**	**15-30**	**0-15**	**15-30**
T_1-CONTROL	7.79	7.80	7.80	7.80	0.11	0.11	0.11	0.11	1.33	1.33	1.66	1.50
T_2-50%NPK	7.77	7.79	7.79	7.80	0.11	0.12	0.11	0.12	1.33	1.33	1.66	1.33
T_3-75%NPK	7.75	7.79	7.74	7.76	0.12	0.12	0.12	0.12	1.33	1.50	1.50	1.66
T_4-100%NPK	7.70	7.75	7.68	7.74	0.13	0.13	0.13	0.13	1.33	1.33	1.33	1.66
T_5-150%NPK	7.69	7.75	7.70	7.75	0.19	0.13	0.21	0.13	1.33	1.50	1.33	1.83
T_6-100%NP	7.71	7.76	7.73	7.78	0.12	0.12	0.12	0.12	1.20	1.33	1.50	1.33
T_7-100%N	7.79	7.85	7.80	7.89	0.11	0.11	0.10	0.10	1.33	1.33	1.66	1.33
T_8-100%NPK-S	7.72	7.79	7.73	7.79	0.13	0.12	0.13	0.12	1.20	1.20	1.33	1.20
T_9-50%NPK+AZO	7.73	7.75	7.73	7.76	0.12	0.12	0.12	0.12	1.33	1.20	1.33	1.33
T_{10}-75%NPK+AZO	7.70	7.75	7.69	7.73	0.13	0.13	0.13	0.13	1.20	1.33	1.33	1.33
T_{11}-100%NPK+AZO	7.68	7.71	7.65	7.70	0.14	0.12	0.14	0.12	1.00	1.33	1.33	1.20
T_{12}-100%NPK+AZO+PSB	7.65	7.70	7.64	7.71	0.16	0.14	0.17	0.14	1.00	1.33	1.20	1.33
T_{13}-50%NPK+FYM	7.75	7.77	7.75	7.77	0.17	0.13	0.17	0.13	1.33	1.33	1.66	1.33
T_{14}-75%NPK+FYM	7.70	7.73	7.69	7.73	0.18	0.14	0.19	0.14	1.20	1.33	1.50	1.33
T_{15}-100%NPK+FYM	7.62	7.71	7.58	7.69	0.20	0.15	0.21	0.16	1.33	1.33	1.20	1.50
T_{16}-100%NPK+FYM+AZO+PSB	7.54	7.52	7.50	7.52	0.23	0.18	0.24	0.18	1.00	1.24	1.00	1.50
SEm±	0.02	0.03	0.02	0.03	0.00	0.01	0.00	0.00	0.01	0.01	0.01	0.02
CD(P=0.05)	0.04	0.09	0.06	0.07	0.01	0.01	0.01	0.01	0.02	0.03	0.03	0.05

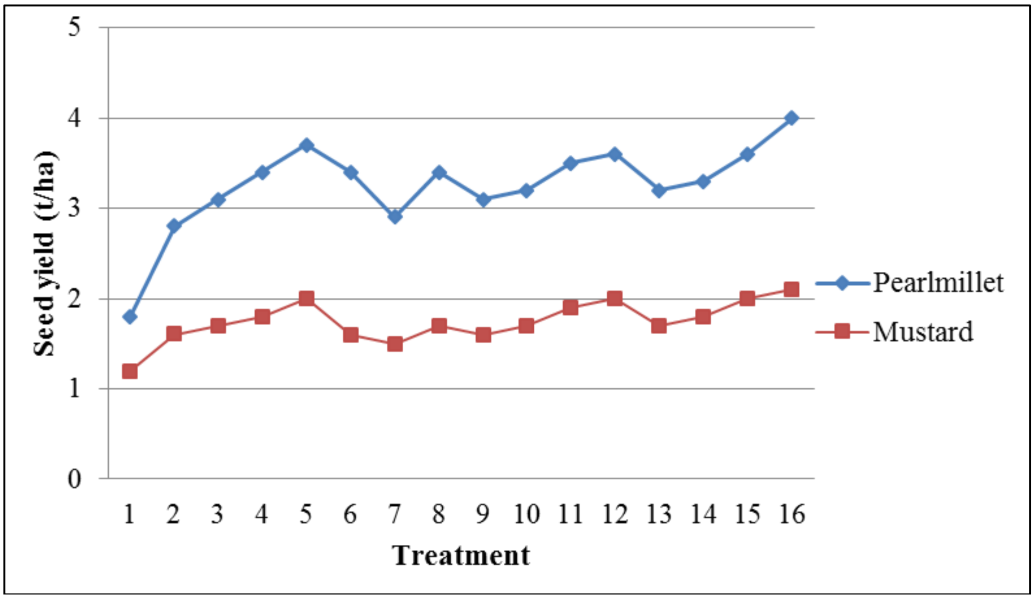
Table 4: Correlation matrix of total grain productivity (pearl millet-mustard 2010-12) with fertility status and physico-chemical properties of surface soil (0-15cm)

	TP	**OC**	**Av.N**	**Av.P**	**Av.K**	**B.D**	**Porosity**	**MWHC**	**$CaCO_3$**
TP	1								
OC	0.601**	1							
Av.N	0.855**	0.810**	1						
Av.P	0.787**	0.839**	0.847**	1					
Av.K	0.835**	0.784**	0.841**	0.882**	1				
B.D	-0.693**	-0.752**	-0.781**	-0.867**	-0.850**	1			
Porosity	0.693**	0.752**	0.781**	0.867**	0.850**	-1.000**	1		
MWHC	0.830**	0.719**	0.791**	0.860**	0.899**	-0.886**	0.886**	1	
$CaCO_3$	-0.721**	-0.704**	-0.780**	-0.824**	-0.785**	0.688**	-0.688**	-0.715**	1

**P= 0.01; TP: total productivity

Productivity

The productivity in terms of seed and straw yield of pearl millet and mustard was increased significantly during the study period (2010-2012) due to various nutrient management practices (fig 1 and 2).The pooled data of seed yield ranged between 1.8 to 4.0 t/ha and 1.2 to 2.1 t/ha and that of straw yields between 4.4 to 8.8 t/ha and 3.5 to 7.0 t/ha for pearl millet and mustard, respectively. The data reveals that by increasing the application of NPK from 50 to 150% resulted in significant increase of average straw and seed yield. Maximum seed and straw yield of pearl millet (4.0 and8.8 t/ha) and mustard (2.1 and 7.0 t/ha) was recorded in treatment 100% NPK+FYM @10 t/ha/year + Azotobacter + PSB followed by treatment 100%NPK+FYM @10t/ha/year by 8.5 and 3.6 (pearl millet) and 6.58 and 2.0t/ha (mustard), whereas lowest in control (pearl millet 4.4 t/ha; mustard 3.5 t/ha). Application of 100%N alone also enhanced the productivity (seed + straw yield) of pearl millet by 37.1 % and mustard by 46.8 % over control; although there was declining trend in crop yield over optimal dose fertility treatment. The inoculation of seed with *Azotobacter* under different NPK levels gave significantly higher straw yield as compared to same level of NPK alone. Application of 100%NPK recorded higher productivity over 100%NP by 11.3% and 8.3% for pearl millet and mustard, respectively while the treatment receiving 100%NPK-S did not show much difference. Application of FYM (@10 t/ha/years) in combination with different inorganic treatments gave significantly higher yield over respective inorganic treatments alone.



Note: 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*, TY_{11}: 100% NPK+ *Azotobacter*, T_{12}: 100% NPK+ *Azotobacter*+ PSB, T_{13}: 50% NPK+ FYM @10 t/ha/year, T_{14}: 75% NPK+ FYM @10t/ha/year, T_{15}: 100% NPK+ FYM @10t/ha/year, T_{15}: 100% NPK+ FYM @10t/ha/year+ *Azotobacter* + PSB

Fig 1: Influence of integrated nutrient management on pooled seed yield of pearlmillet and mustard (2010-12)

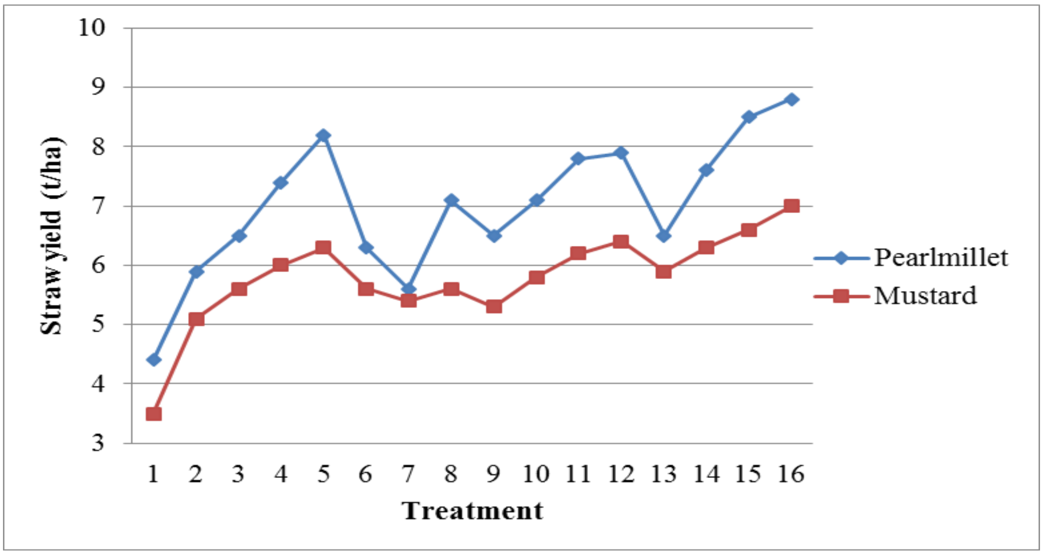


Fig 2: Influence of integrated nutrient management on pooled straw yield of pearl millet and mustard (2010-12)

Relationship of crop productivity with fertility and soil properties

Simple correlation coefficients obtained between crop productivity with fertility status and soil physico-chemical properties are presented in Tables 4. The association of total productivity (TP) as seed yield of pearl millet +mustard was highly positive and significant with major available nutrients as available N (r = 0.855**), P (r = 0.787**), K (r = 0.835 **) and maximum water holding capacity (r = 0.830**); where as moderately positive significant correlation was observed with soil organic carbon (r = 0.601**) and soil porosity (r = 0.693**). Similar results were obtained by Katkar *et al.* (2011) for crop productivity with major available nutrients and organic carbon status under long-term fertility experiment on sorghum - wheat system in Vertisols. The percent calcium carbonate (r = 0.721**) content and bulk density (r = -0.693**) showed negative and moderately significant correlation with total productivity. This indicated that total productivity of pearl millet- mustard cropping was enhanced and control by major available nutrients, organic carbon and other physico-chemical parameters.

The integration of optimal dose of chemical fertilizer in combination with farmyard manure @10t/ha/year and bio fertilizers enhance the fertility status of soil improve its physico-chemical parameters and increased the crop productivity over supper optimal to optimal, other fertility treatments and unfertilized control under pearl millet-mustard cropping system during two years of study.

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