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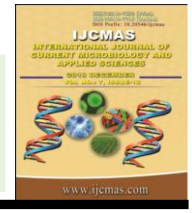

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Effect of Integrated Potassium Management on Soil Biological Properties and Yields of Corn under Corn-Wheat Cropping System

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ABSTRACT

Potassium fertilization is often ignored in cereal-based cropping systems assuming sufficient K reserves in the alluvial soils of north-western India. However, the responses to K have now widely reported due to continuous mining and little additions through external sources. Little known on the effects of integrated K management on soil biological properties and yield performance of corn grown in sequence with wheat. A field experiment was conducted during 2010-2012 to find out the performance of corn (*Zea mays* L.)–wheat (*Triticum aestvum* L. emend Fiori & Paol.) cropping system with K fertilization through muriate of potash and farmyard manure (FYM) at New Delhi, India. The experiment was laid out in the randomized block design with seven treatments replicated thrice. Results revealed that treatment applied with 90 kg K supplemented 60 kg K through MOP and 30 Kg K through FYM significantly increase grain yield (100.9% and 99.3%) and stover yield (45.8% and 33.6%) during 2010 and 2011 respectively in the corn crop. A positive correlation observed between yield and soil biological properties, *viz.*, bacterial population, actinomycetes, cellulose degrading bacteria, phosphorus solubilizing bacteria, potassium solubilizing bacteria, dehydrogenase activity, phosphatase activity, fluorescein diacetate and β-glucosidase. It concluded that application of FYM could be an alternative option for sustainable management of agricultural land and restore its fertility compared to the use of K fertilizers.

Introduction

Corn is among the important cereal crops to meet food, feed, fodder and industrial needs of the country. It is often grown in sequence with wheat in the alluvial soils of north-western India. The corn-wheat cropping is very exhaustive regarding nutrient removal from the soil. Again, due to the imbalanced application of vital nutrients like N and P, the K is becoming deficient in soils. Removal of K in proportion to N is very high in cropping systems, particularly in those involving cereal and fodder crops. It has been observed that even with the recommended levels of fertilizer application, there is enormous negative K balance under different cropping systems (Yadav *et al.,* 1998).

Potassium (K) is one of the vital nutrients for growth and yield of crops. Most of the crops absorb a significant amount of K from the rhizospheric soil through roots (Steingrobe and Claassen, 2000). It plays a crucial role in antagonistic and synergistic interaction with other essential nutrients (Dibb and Thompson, 1985). Potassium improves root growth, drought resistance, and enhances translocation and assimilation of nutrients, resulting in the production of starch and protein-rich grain, and reduction of crop lodging and diseases (Dobermann, 2001; Polara *et al.,* 2009; Nejad *et al.,* 2010).

Soil biological activity is a driving force in degradation and conservation of exogenous plant material and anthropogenic depositions, transformations of organic matter, and evolution and maintenance of soil structure (Canarutoo *et al.,* 1995; Bandick and Dick, 1999). The activity of secondary trophic levels depends upon the energy obtained by primary decomposers of organic matter in soils. In turn, this activity plays a primary function in nutrient cycling and support of plant life (Clarholm and Rosengren-Brinck, 1995; Bolata *et al.,* 2003). The population of microbes and enzymatic activity in the soil play a crucial role in maintaining soil fertility and its health through bringing changes by their biochemical processes (Nannipieri *et al.*, 2003; Okore *et al.*, 2012).

The present study was conducted to study the effect of the application of integrated K fertilization on soil biological activities (enzymatic activity and microbial population) and crop yield under corn-wheat cropping system.

Materials and Methods

Experimental site

The field experiment conducted on corn during the rainy season (*July-October*) and wheat during the winter season (November-April) of 2010-11 and 2011-12 at research farm of Indian Agricultural Research Institute, New Delhi (India) situated in north-western India (28.35 N, 77.12' E) and at 229 m above mean sea level. The daily minimum and maximum temperatures during the growth period of corn ranged between 19.8°C and 38.5°C, respectively during 2010, while in 2011, it ranged between 22.0°C and 38.2°C. The total rainfall received during the corn growing season of 2010 and 2011 was 763 and 465 mm with 35 and 30 rainy days, respectively. High intensity and uneven distribution of rain observed during *rainy* season 2010; whereas the intensity was low, and distribution of rainfall was even in *rainy* season 2011.

The daily minimum and maximum temperatures during the growing period of wheat were 2.0°C and 35.4°C, respectively during 2010-11. In 2011-12, daily minimum and maximum temperatures ranged from 0 to 39.0°C. Wheat crop received 65.6 mm rainfall with 11 rainy days during 2010-11and 40.8 mm rainfall with 4 rainy days during 2011-12.

The experimental soil characterized as sandy loam having pH 8.0, EC 0.43 dSm^{-1} organic carbon 0.4 % available N 173.3 kg ha^{-1}, available P 13.8 kg ha^{-1} and available K 261 kg ha^{-1}. The experiment was carried out in the randomized block design with three replications. Seven treatments were applied to corn (M) in the rainy season and wheat (W) in the winter season at the fixed site. Recommended doses of 150 kg N ha^{-1} and 26 kg P ha^{-1} applied to corn through urea and diammonium phosphate (DAP), respectively. The full dose of P and K applied as basal, whereas 50 kg N ha^{-1} was given as basal and remaining 100 kg N ha^{-1} was applied in two equal splits at 30 and 60 days after sowing (DAS). Muriate of potash (MOP) and farmyard manure (FYM) used as sources of K. Wheat was given 120 kg N ha^{-1} through urea and 26 kg P ha^{-1} through DAP. The FYM applied analyzed for N, P, K content and recorded 5 and 6 g N kg^{-1}, 4 and 4 g P kg^{-1} and 5 and 4 g K kg^{-1} FYM applied in the field during 2010 and 2011, respectively. The amount of N, P, and K applied through urea, DAP and FYM were adjusted in all the treatments to maintain the required nutrient combinations. The final amount of N, P and K had given to corn and wheat crop as shown in Table 1. The corn hybrid 'PEHM2' (CM137 X CM138) was sown at 60 cm x 20 cm spacing, using 20 kg seed ha^{-1}. The wheat variety 'HD 2967' resistant to rust with a moderate level of resistance to the Ug_{99} race of stem rust was selected for this study.

Microbial count and enzymatic activity in soil

For microbial and enzymatic studies, the soil collected from the rhizosphere of crop plants at maturity. The microbial population counted by preparing appropriate serial dilutions for bacteria, actinomycetes, P solubilizers, K solubilizers and cellulose degraders. The nutrient agar, Kenknight and Munaier's agar, Pikovaskiya agar, Aleksandrov medium and carboxymethyl cellulose (CMC) agar media were used for enumeration of bacteria, actinomycetes, P solubilizers, K solubilizers and cellulose degraders respectively. The dehydrogenase activity and fluorescein diacetate (FDA) was calculated by following Green *et al.,* (2006) and Klein *et al.,* (1971), respectively. Acid phosphatase and alkaline phosphatase activities were determined colorimetrically by a visible spectrophotometer (Tabatabai and Bremner, (1969). β-glucosidase activity was estimated colorimetrically by a visible spectrophotometer (Evazi and Tabatabai, 1988).

Chemical soil and plant analysis

Soil samples were collected from the field and mixed thoroughly, air-dried, sieved and analyzed for available N by alkaline $KMnO_4$ method (Subbiah and Asija, 1956), 0.5 N Na-bicarbonate extractable P (Olsen *et al.,* 1954), and 1.0 N NH_4OAc–extractable K (Jackson,1967).

Measurement of plant growth parameters and yield of corn

Harvesting of corn and wheat was carried out in an area of 4.8 m^2 and 4.5 m^2 from the center of each plot manually. Dry weights of stems and grains were measured separately. The grain and stover/straw yield calculated through the weight of dried plant samples and converted in ton per hectare.

Statistical analysis

The experimental data analyzed by applying the "Analysis of Variance" technique for randomized block design (Gomez and Gomez 1984). The standard error of mean (SEm$\pm$), least significant difference (LSD) at $P \leq 0.05$ probability were worked out. The correlation studies performed using SPSS programme (version 16.0).

Results and Discussion

Yields of corn and wheat

Grain and stover yield of corn differed significantly due to K application (Table 2). All the treatments supplied with K showed significant superiority over no K treatments for grain yield. The corn gave the highest grain yield of 4.44 t ha^{-1} (2010), and 5.42 t ha^{-1} (2011) under treatment applied with 90 kg K ha^{-1} supplemented 60 kg K through MOP and 30 kg K ha^{-1} through FYM (T_3). The treatment T_3 produced 27.7% and 19.4% higher yield over T_2 and T_4 during 2010, and 10.8% and 12.4%, during 2011, respectively.

The treatment T_2 and T_4 applied with 30 kg K ha^{-1} through FYM+30 kg K ha^{-1} through MOP also proved significantly superior over treatment T_5 and T_6 which involved 60 kg K though MOP alone. Stover yield followed the trend of grain yield during 2010, whereas during 2011, all the treatments applied with K were found at par with each other and significantly superior to control (T_1). On the other hand, the highest grain yield of wheat was obtained with treatment applied with 90 kg K ha^{-1} supplemented 60 kg K through MOP and 30 kg K ha^{-1} through FYM (T_7) during 2010-11 (5.39 t ha^{-1}) and 2011-12(5.49 t ha^{-1}). Treatment T_7 also gave the highest straw yield of 8.20 t/ha and 8.98 t/ha, respectively.

Nutrient availability in rhizospheric soil

A decline in the availability of different nutrients in the soil, irrespective of treatments applied over the initial amount of nutrients (Table 3). All the treatments applied with integrated K management showed a significant increase in nutrient availability over the remaining treatments compared with treatment applied with K through MOP alone and treatment applied with no K (T_1). During 2010 and 2011, treatment applied with 60 kg K ha^{-1} supplemented 30 kg K ha^{-1} through MOP and 30 kg K ha^{-1} through FYM in corn and 60 kg K ha^{-1} in wheat crop through MOP alone ($T_{2)}$ showed highest N (188.3 kg ha^{-1} and 190.0 kg ha^{-1}) and P availability (14.7 kg ha^{-1} and 15.4 kg ha^{-1}).

The treatment (T2) followed by treatment applied with 60 kg K ha^{-1} supplemented 30 kg K ha^{-1} through MOP and 30 kg K ha^{-1} through FYM in corn and no K in wheat crop ($T_{4)}$ and treatment applied with 90 kg K ha^{-1} supplemented 60 kg K ha^{-1} through MOP and 30 kg K ha^{-1} through FYM in corn and no K in wheat crop (T_3). Availability of K was the highest in treatment T_3 (258.9 kg/ha and 239.3 kg/ha), which showed significant superiority over remaining treatments.

Microbial count

The significant increase observed in the total bacterial count, P solubilizers, actinomycetes, cellulose degraders and K solubilizing bacteria in treatments applied with integrated K management (Fig. 1).

Highest bacterial counts, P solubilizers, actinomycetes, cellulose degraders and K solubilizing bacterial counts recorded in treatment applied with 90 kg K ha^{-1} supplemented 60 kg K ha^{-1} through MOP and 30 kg K ha^{-1} through FYM in corn and no K in the wheat crop (T_3).

The treatment T_3 followed by treatment applied with 60 kg K ha^{-1} supplemented 30 kg K ha^{-1} through MOP and 30 kg K ha^{-1} through FYM in corn and 60 kg K ha^{-1} in wheat crop (T_2) and treatment applied with 90 kg K ha^{-1} supplemented 30 kg K ha^{-1} through MOP and 30 kg K ha^{-1} through FYM in corn and no K in wheat crop (T_4).

Enzymatic activity

All the treatments applied with integrated K management showed the significant increase in dehydrogenase activity, FDA activity, β-glucosidase activity, acid phosphatase and alkaline phosphatase activity (Fig. 2).

The treatment applied with 90 kg K ha^{-1} supplemented 60 kg K ha^{-1} through MOP and 30 kg K ha^{-1} through FYM in corn, and no K in the wheat crop (T_3) showed significant superiority over all the treatments for dehydrogenase activity, FDA activity, β-glucosidase activity, acid phosphatase and alkaline phosphatase activity.

Pearson's correlation matrix between yield, and enzymatic activities and microbial count

Significant and positive correlations were observed (*P=0.01*) between yield with bacterial count (r=0.812), P solubilizers (r=0.798), actinomycetes (r=0.705), cellulose degraders (r=0.799), K solubilizing bacteria (r=0.752), dehydrogenase activity (r=0.814), FDA(r=0.752), β- glucosidase (r=0.803), acid phosphatase (r=0.825), alkaline phosphatase (r=0.758) as shown in (Table 4).

Table.1 Designing of various treatments for integrated potassium fertilization under corn-wheat cropping system

Symbol	Treatment detail	Crop	Amount of nutrient applied (kg/ha)		
			N	**P**	**K**
T_1	K_0 (C)– K_0 (W)	Corn (C)	150	26	0
		Wheat (W)	120	26	0
T_2	MOP_{30}+FYM_{30}(C)–MOP_{60}(W)	Corn (C)	150	26	60
		Wheat (W)	120	26	60
T_3	MOP_{60}+FYM_{30}(C)–K_0(W)	Corn (C)	150	26	90
		Wheat (W)	120	26	0
T_4	MOP_{30}+FYM_{30}(C)–K_0(W)	Corn (C)	150	26	60
		Wheat (W)	120	26	0
T_5	MOP_{60} (C)– MOP_{30} + FYM_{30} (W)	Corn (C)	150	26	60
		Wheat (W)	120	26	60
T_6	MOP_{60} (C)–MOP_{60} (W)	Corn (C)	150	26	60
		Wheat (W)	120	26	60
T_7	K_0 (C)–MOP_{60}+FYM_{30} (W)	Corn (C)	150	26	0
		Wheat (W)	120	26	90

Table.2 Effect of integrated K fertilization on yield (t ha^{-1}) of corn and wheat

Treatment	Corn				Wheat			
	Grain		**Stover**		**Grain**		**Straw**	
	2010	**2011**	**2010**	**2011**	**2010-11**	**2011-12**	**2010-11**	**2011-12**
T_1	2.21	2.72	4.48	5.26	3.80	3.89	7.30	7.59
T_2	3.68	4.89	5.90	6.75	4.94	5.05	8.13	8.53
T_3	4.44	5.42	6.53	7.03	4.22	4.31	7.78	8.09
T_4	3.72	4.82	5.83	6.62	4.10	4.19	7.76	8.07
T_5	2.99	4.30	5.14	6.53	5.05	5.16	8.14	8.77
T_6	3.02	4.21	5.21	6.43	4.81	4.88	7.93	8.24
T_7	2.21	3.20	4.47	5.83	5.39	5.49	8.20	8.98
LSD	0.57	0.61	0.50	0.78	0.45	0.47	NS	NS

Note: for treatment details (T_1 to T_7) see Table 2.

Table.3 Effect of integrated potassium fertilization on nutrient availability after corn harvest

Treatment	Available N		Available P		Available K	
	2010	**2011**	**2010**	**2011**	**2010**	**2011**
T_1	166.3	157.4	13.6	12.9	217.5	177.9
T_2	188.3	190.0	14.7	15.4	250.6	228.6
T_3	179.2	176.2	14.5	14.5	258.9	239.3
T_4	187.8	186.2	14.7	14.7	251.0	221.8
T_5	169.3	177.3	14.5	15.2	235.1	213.2
T_6	169.2	158.6	14.6	14.5	233.9	207.1
T_7	165.4	174.4	13.6	14.0	217.5	200.0
LSD ($P=0.05$)	7.9	5.7	0.4	0.6	8.0	9.4

Table.4 Pearson's correlation matrix between yield, microbial count and enzymatic activities in rhizospheric soil after harvest of corn (mean of two years)

Parameter	Grain yield	Bacterial count	Phosphorus solubilizers	Actino-mycetes	Cellulose degraders	K solubilizing bacteria	Dehydrogen-ase activity	FDA	Beta glycosidase	Acid phosphatase	Alkaline phosphatase
Grain Yield	1	0.812**	0.798**	0.705**	0.799**	0.752**	0.814**	0.752**	0.803**	0.825**	0.758**
Bacterial Count		1	0.999**	0.978**	0.988**	0.972**	0.981**	0.959**	0.976**	0.989**	0.969**
Phosphorus solubilizers			1	0.982**	0.983**	0.9784**	0.973**	0.954**	0.969**	0.983**	0.964**
Actinomycetes				1	0.953**	0.983**	0.940**	0.960**	0.952**	0.955**	0.961**
Cellulose degraders					1	0.941**	0.994**	0.935**	0.968**	0.990**	0.950*
K solubilizing bacteria						1	0.918**	0.916**	0.917**	0.937**	0.917**
Dehydrogenase activity							1	0.952**	0.984**	0.997**	0.965**
FDA								1	0.990**	0.967**	0.997**
Beta glycosidase									1	0.991**	0.995**
Acid phosphatase										1	0.976**
Alkaline phosphatase											1

* Significant at the P≤0.05 (2-tailed); ** Significant at the P≤0.01(2-tailed)

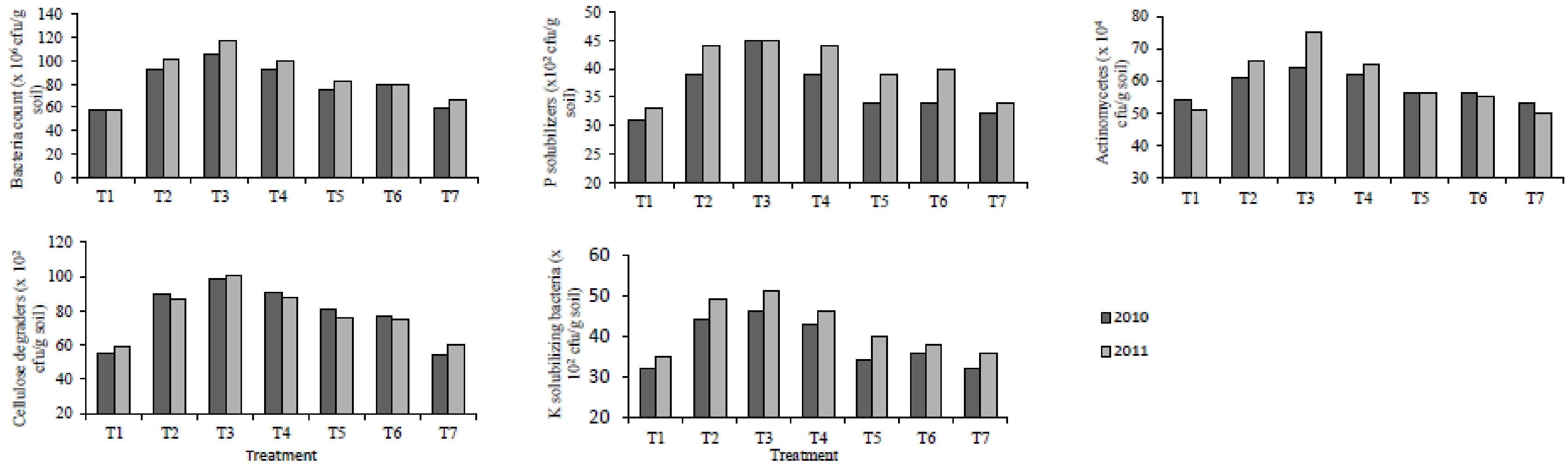

Fig.1 Effect of integrated potassium fertilization on microbial counts in rhizospheric soil

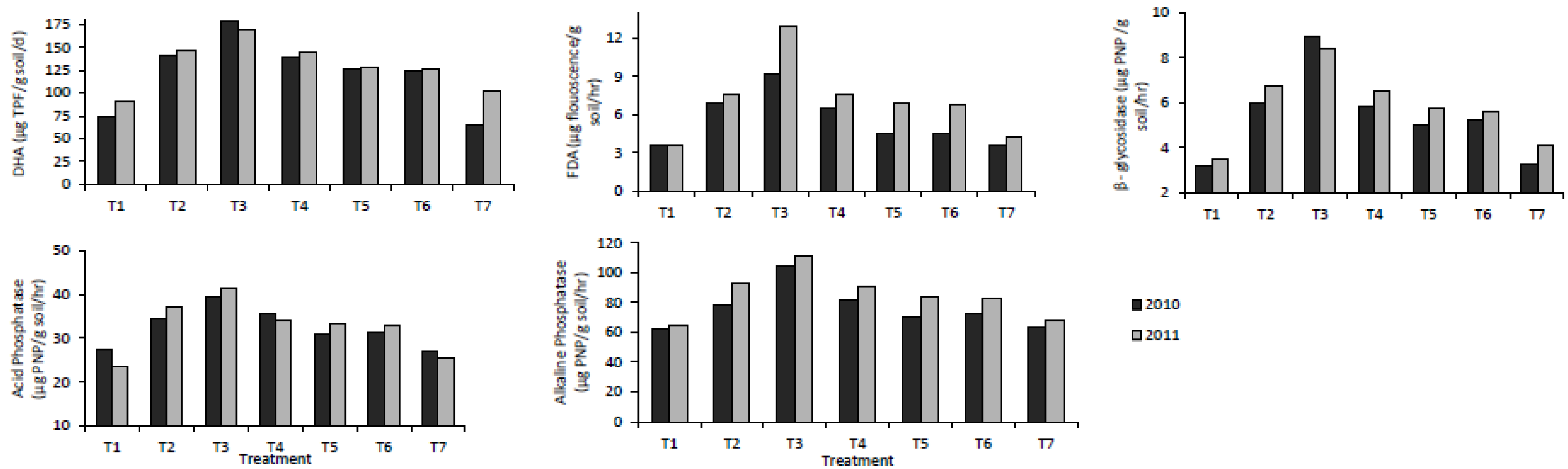

Fig.2 Effect of integrated potassium fertilization on enzymatic activity in rhizospheric soil

Crop productivity

Results indicate that all the treatments applied with K showed significant improvement in the yield of corn and wheat crops (Table 2). The highest yield observed in treatment applied with 90 kg K ha^{-1} supplemented 60 kg K ha^{-1} through MOP and 30 kg K ha^{-1} through FYM (T_3) in corn and treatment applied with 90 kg K ha^{-1} supplemented 60 kg K ha^{-1} through MOP and 30 kg K ha^{-1} through FYM (T_7) in wheat crop. The application of 90 kg K ha^{-1} improved the availability of K in the soil. The available K is vital to many plant processes including photosynthesis, translocation of photosynthates, protein synthesis, activation of plant enzymes (IPNI, 1998). Again, integrated K management involving FYM supplied N, P and K in available forms to the plants through biological decomposition along with micronutrients leading to higher yields. Kumar *et al.,* (2014) reported that integrated use of K (FYM +MOP) recorded significantly higher yield compared to 100% NP and 100% NPK fertilizers due to greater availability of macro and micronutrients. Rehman *et al.,* (2008) reported that different levels of NPK and FYM alone or in combination had a significant effect on yield of the wheat crop. Mehdi *et al.,* (2001) reported that increasing K application resulted in a significant increase in growth and yield of wheat.

Nutrient availability

Availability of N, P, and K declined after harvest of corn (Table 3). The continuous mining of nutrient by the crop resulted in the decline in the nutrient availability irrespective of applied nutrient (Ramamurthy *et al.,* 2009, NAAS report 2006). In the present study, the availability of different nutrients increased due to the slow-release supply of organically-bound nutrients such as N, P through integrated K management practice (Mariangela and Francesco 2010; Choudhary and Kumar 2013). Addition of FYM through integrated K management accelerates the process of mineral weathering and aids insolubilization of plant nutrients from otherwise insoluble minerals. Further, FYM provides slowly available C and energy source to support a large diverse, metabolically active microbial community, which helps in solubilization and availability of nutrients to crop plants (Wolf and Wagner 2005).

Microbial counts

Microorganisms have high surface: volume ratio, due to which, they have intimate relations with their surroundings. A change in microbial activity is considered as an indicator for soil improvement and transient changes to various perturbations (Pankhurst *et al.,* 1995). In the present study, increase in the population of bacteria, actinomycetes, P solubilizers, cellulose degraders and K solubilizing bacteria observed under the treatments applied with integrated K compared to treatments applied with K through MOP alone or No K treatment (Fig. 1). Compared to chemical fertilizers, integrated K had a significantly greater impact on the microbial biomass and activity. Firstly, the integrated K application provided abounding organic matter for the growth and development of living microorganisms in the soils. Secondly, integrated K application helped in the better growth of plant roots, which also added soil organic matter in the soil for microorganisms (Gong *et al.,* 2009).

Enzymatic activity

Different enzymes in soil play vital roles. Dehydrogenase activity is considered a good indicator of microbial activity as it reflects the total range of oxidative activity of soil microflora (Nannipieri *et al.,* 1990).

Phosphatases are important as they help in the release of P from organic P (Taylor and Sinsabaugh, 2015). β-Glucosidase is an enzyme involved in biomass degradation and regarded as an early indicator of changes in soil properties (Ekenler and Tabatabai, 2003). Fluorescein diacetate [3', 6'-diacetyl fluorescein (FDA)] assay has been widely used to assess overall hydrolytic activities of soil microbial communities including bacteria and fungi (Alkorta *et al.*, 2003; Liu *et al.*, 2007). Integrated application of K increased the activity of different enzymes compared to treatments applied with K through MOP alone or in the treatments applied with No K (Fig. 2). The increase in enzymatic activity under integrated K application was due to more availability of easily decomposable components (organic C) in the form of FYM for the metabolism, growth, and development of soil microorganisms (Gopinath *et al.*, 2007; Gong *et al.*, 2009; Burns *et al.*, 2013). Higher enzymatic activity in treatments applied with K through MOP alone recorded due to the greater input of root biomass due to better crop productivity which was the result of higher availability in soil for better growth and development of corn plants (Usha *et al.*, 2013; Singh *et al.*, 2015; Heidari *et al.*, 2016).

Correlation studies

The positive correlation showed that enzymes activities and microbial count played a significant role in yield improvement (Table 4). The activity of microbes and enzymes helps in biomass transformations of the release of nutrients. The increase in microbial activity indirectly showed an increase in microbial biomass which acted as a small but labile reservoir for these elements.

It concluded that integrated K management significantly increases grain and stover/straw yield of corn-wheat cropping system. Integrated K management significantly improves the soil biological properties. A direct correlation observed between yield and soil biological properties. Integration K management could be an alternative option for sustainable management of agricultural land and restore its fertility compared to the application of K fertilizers alone.

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