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Effect of fertilizer treatments on jute (*Chorchorus olitorius*), microbial dynamics in its rhizosphere and residual fertility status of soil

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ABSTRACT

The effect of various fertilizer treatments on jute (*Corchorus olitorius*) and their residual effect on soil fertility along with the microbial dynamics in jute rhizosphere were studied during 2008-11. Application of recommended dose of fertilizer (100 % NPK) was sufficient for jute fibre yield while nutrient uptake was significantly higher with 150% NPK but at par only with 100% NPK + 10 tonnes FYM/ha when N and P are considered. The population of beneficial microbes and enzymatic activities, viz. dehydrogenase, urease, fluorescein diacetate hydrolyzing activity, acid and alkaline phosphatase in jute rhizosphere after 60 days of sowing were significantly higher with 100% NPK + 10 tonnes FYM/ha over all treatments including 100 and 150% NPK. The soil microbial biomass carbon and basal soil respiration rate in jute rhizosphere followed the same trend as that of enzyme activities. There was build up of residual soil fertility after three years in all the treatments except control and 50% NPK compared to initial status and the application of 100% NPK with 10 tonnes FYM/ha helped in higher residual status of organic carbon, available N, P and K in soil. Integration of recommended dose of fertilizer with 10 tonnes FYM/ha proved to be the best possible option for sustainable jute fibre production and maintenance of soil microbial health and fertility status.

Key words: Fertilizer, Fibre yield, Jute, Microbial dynamics, Nutrient uptake, Residual effect, Rhizosphere

Jute (*Corchorus olitorius* L.) is the second most important annual fibre crop, next to cotton in India. Jute is mostly cultivated in eastern India comprising the states of West Bengal, Bihar, Odisha, Asom, Tripura, Meghalaya and eastern part of Uttar Pradesh covering an area of about 0.85 million ha. India is the largest producer of jute fibre (40% of world production) and jute goods (60% of global production) in the world with an average productivity of about 23 q fibre/ha. Sustainable production of jute depends greatly on the soil fertility management which involves adequate and balanced nutrient supply through a combination of chemical fertilizers and organic sources like organic manures, compost, green manure, bio-fertilizer etc. available at farmers' disposal.

Jute is highly responsive to chemical fertilizer and organic manures. Use of chemical fertilizers has positive as well as negative effect on soil microbial population and their activities. Soil organisms act as primary driving agents of nutrient cycling, regulating the dynamics of soil organic matter, soil carbon sequestration and greenhouse gas emissions, modifying soil structure and water regimes, enhancing the amount of nutrient acquisition by vegetation; conferring stress tolerance, resisting pathogens and improving plant health (Rao 2007). Organically farmed soils had greater microbial abundance and activity compared to chemically fertilized soils but the ability of microbial communities did not differ in degradation of organic matter in both soils (Gunapala *et al.* 1998). Continuous application of only nitrogen or nitrogen plus phosphorus was found to decrease particulate organic matter, soil respiration, microbial biomass C and N, which were, however, improved significantly on addition of NPK or NPK + organics (Manna *et al.* 2005). Microbial activities affect nutrient cycling and the availability of inorganic nutrients. Soil enzymes and microbial biomass have been considered as major indicators of soil quality due to their relationship to soil fertility and high sensitivity to changes originated by the management and environmental factors (Diosma *et al.* 2006).

Rhizosphere is the primary site for all microbial activities in the jute grown soil. The effect of application of chemical fertilizers/manures etc. on the microbial communities in jute rhizosphere has not been adequately reported. Currently our understanding of microbial dynamics

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associated with jute rhizosphere is very limited, which hinders effective crop management. Present study was therefore, undertaken to find out effect of various fertilizer treatments on fibre yield, nutrient uptake by jute and residual soil fertility, beneficial microbes, enzyme activities, microbial biomass and basal soil respiration rate in jute rhizosphere.

MATERIALS AND METHODS

The field experiment was conducted during 2008-11 at the same site of the research farm of Central Research Institute for Jute and Allied Fibres, Barrackpore, West Bengal situated at $22^0\ 45^/$ N latitude, $80^0\ 26^/$ E longitude with an altitude of 9.2 m above mean sea level. The soil of the experimental field was sandy loam in texture with pH 7.5. Soil organic carbon was estimated at 5.8 g/kg and soil available N, P_2O_5 and K_2O were estimated at 275, 35 and 170 kg/ha respectively. Soil samples were analysed following standard procedures (Page *et al.* 1982). Average annual rainfall received during cropping years was 1155.4 mm. The field experiment was laid out in a randomized block design with four replications and six treatments, viz. T_1, control, T_2, 50% of the recommended dose of NPK, T_3, 100% of the recommended dose of NPK, T_4, 100% of the recommended dose of NPK + 10 tonnes farmyard manure (FYM)/ha, T_5, 150% of the recommended dose of NPK and T_6, soil test crop response equation based recommended dose. The recommended dose of NPK for jute was N: P: K: 60: 30: 30 kg/ha. Sources of N, P and K fertilizers were urea, single super phosphate and muriate of potash respectively for all the treatments. The N, P and K dose for T_6 was 75 kg N, 40 kg P and 40 kg K/ha on soil test crop response equation basis. Phosphatic and potassic fertilizers were applied as basal dose during land preparation. Nitrogenous fertilizer was applied in two equal split doses. The 1st split of N was applied 21 days after emergence of the crop and the second one was applied 2 weeks after the first split application. In treatment T_4, well decomposed farmyard manure containing 0.50, 0.30 and 0.65% of N, P and K respectively was applied and mixed well in the soil 15 days prior to sowing of the crop.

Olitorius jute (cv JRO 524) was sown with a seed rate of 5 kg/ha maintaining a row to row and plant to plant spacing of 25 and 5 cm respectively during 2nd week of April in each year. Need based irrigation was given to the crop and the crop was harvested at maturity 120 days after sowing. The jute crop after harvest was kept for 3 days in the field for defoliation of the leaves. The jute plants were then placed in retting tank. After completion of retting within 20 days, the fibre was extracted and washed in clean water, sun-dried and dry weight of the fibre was taken. The plant samples were collected at harvest and dried, processed and analyzed for total N, P and K following standard procedures (Tandon 1993). At the time of harvest, surface soil samples (0-15 cm) were collected. The jute rhizosphre soil samples were collected 30 days after sowing (DAS) onwards at 30 days interval from each plot by carefully up rooting of five plants at random keeping the root system intact. The soil strongly adhering to the roots was immediately used without drying for determination of various soil biological properties.

The enumeration of beneficial microbes was done on agar plate containing appropriate media following serial dilution technique and pour plate method (Parmer and Schmidt 1966). For *Azotobacter*, Ashby's mannitol agar media, for *Aspergillus*, *Penicillium* and *Trichoderma* Rose Bengal agar media and for phosphate solubilizing microbes, Pikovskaya's agar media (Pikovskaya 1948) were used. The phosphate solubilizing power of the rhizosphere soils was determined by estimating soluble phosphorus after incubating 1 g soil in culture tubes for 7 days, at 30 ± 1^0 C in 15 ml Pikovskaya's broth, containing insoluble phosphate, followed by estimation of soluble phosphorus in the broth. The enzyme activities, viz. dehydrogenase, urease, acid and alkaline phosphatase in rhizosphere soil samples were estimated by the method prescribed by Tabatabai (1994). The fluorescein diacetate hydrolyzing activity (FDHA) in soil was measured by the method of Alef (1995b). The soil microbial biomass carbon (SMBC) was estimated following chloroform fumigation extraction method (Vance *et al.* 1987). The basal soil respiration rate (BSRR) was measured by the method of Alef (1995a). The statistical analysis of the experimental data was carried out by using SPSS package (version 10.0). Simple correlation coefficient between soil properties and enzymatic activities were analyzed to see the probable statistical relationship as per Chandel (2004).

RESULTS AND DISCUSSION

Fibre yield of jute

The fibre yield data of each year and as well as pooled data indicated that recommended dose of NPK (T_3) was sufficient for jute fibre production as increment in NPK dose (T_5) or addition of FYM (T_4) did not increase the jute fibre significantly over recommended dose of NPK (Table 1). Among the treatments, 150% NPK recorded highest fibre yield in each year, but it was statistically at par with all the treatments except T_1 and T_2 indicating the fact that higher doses of NPK over the recommended dose did not have any economic advantage in fibre yield as 150% NPK application increased the fibre yield by only 7.6% over 100% NPK.

Nutrient uptake by jute

The pooled data on nutrient uptake (Table 1) by jute crop indicated significant increase in N, P and K uptake with various fertilizer treatments over control. The highest nutrient uptake was observed with 150% NPK which was significantly superior over all other treatments and at par with 100% NPK + FYM when N and P uptake are considered. The significantly lower N, P and K uptake by T_1 and T_2 might be due to improper growth and lower absorption of nutrients because of limited supply.

Table 1 Effect of various fertilizer treatments on fibre yield and nutrient uptake by jute

Treatment	Fibre yield (q/ha)				Nutrient uptake (kg/ha)		
	2008-09	2009-10	2010-11	Pooled	N	P	K
T_1 Control	16.60	15.50	14.05	15.40	35.10	15.40	73.10
T_2 50% NPK	22.20	24.70	26.30	24.40	74.90	23.10	119.0
T_3 100% NPK	31.80	30.00	29.20	30.30	95.40	27.20	137.90
T_4 100% NPK + 10 t FYM/ha	34.00	32.40	30.65	32.40	105.90	28.20	146.20
T_5 150% NPK	34.20	32.70	31.30	32.70	108.60	29.40	164.00
T_6 STCR based recommended dose	31.80	32.00	31.00	31.60	102.40	25.90	139.20
CD (P=0.05)	4.50	4.40	4.70	3.80	3.15	2.20	3.90

Table 2 Effect of various fertilizer treatments on population of beneficial microbes in jute rhizosphere (three years pooled data at 60 DAS*)

Treatment	*Azotobacter* (cfu × 10^5/g oven dry soil)	*Aspergillus*	*Penicillium* (cfu × 10^3/g oven dry soil)	*Trichoderma*	PSM	Phosphate solubilizing power (ppm)
T_1	23.2	18.0	12.0	26.0	5.8	3.50
T_2	25.0	20.0	23.0	30.0	6.6	3.40
T_3	31.8	32.0	42.0	48.0	16.9	5.50
T_4	33.5	50.0	45.0	49.0	17.3	5.80
T_5	28.2	16.0	32.0	32.0	6.8	3.00
T_6	28.5	26.0	35.0	42.0	11.5	3.80
CD (P=0.05)	4.2	5.6	4.8	5.0	3.50	1.70
Initial status	25.5	2.1	2.3	3.9	6.5	2.5

*The microbial population was maximum at 60 DAS, so the data of only 60 DAS is given in the table

Beneficial microbes in jute rhizosphere

The population of beneficial microbes in jute rhizosphere at 60 DAS increased significantly with recommended dose of fertilizer and followed by a decrease with 150% NPK application (Table 2). The population of nitrogen fixing bacteria *Azotobacter*, beneficial fungi *Trichoderma* and phosphate solubilizing microbes (PSM) was significantly higher with 100% NPK + FYM and was at par with T_3 whereas T_4 recorded significantly higher population of *Aspergillus* and *Penicillium* over other treatment combinations.

The higher population of beneficial microbes in 100% NPK + FYM might be due to the maintenance of water stable aggregates, organic matter especially particulate organic matter and availability of respirable substances for microorganisms (Rupela *et al*. 2005, Mandal 2005 and Sharma *et al.* 2011). The population of *Azotobacter* and PSM showed significant correlation (Table 4) with SMBC, organic carbon and enzymatic activities. Application of 100% NPK + FYM recorded significantly higher phosphate solubilizing power but was at par with 100 and 150% NPK.

Enzymatic activities in jute rhizosphere

Dehydrogenase activity

The pooled dehydrogenase activity in jute rhizosphere (Table 3) increased with applied NPK over control and the highest activity (7.2 mg TPF/g oven dry soil) was recorded in 100% NPK + FYM treatment which was significantly superior over T_1 and T_2 but was at par with T_3, T_5 and T_6. The higher dehydrogenase activity 100% NPK + FYM in soils had been attributed to the fact that enzyme activities directly associated with organic matter and microbial response to soluble sugars of the added materials (Hojati and Nourbakhsh 2006). This was in agreement with the findings of Rao (2007) and Sharma *et al*. (2011). A positive correlation (Table 4) between dehydrogenase with organic carbon ($r = 0.66^{**}$), SMBC ($r = 0.594^{**}$), BSRR ($r = 0.591^{**}$), *Azotobacter* ($r = 0.536^{*}$) and PSM ($r = 0.534^{*}$) population supported the fact.

Urease activity

Application of 100% NPK + FYM recorded the maximum urease activity (169.4 mg urea hydrolyzed/g oven dry soil) which was significantly superior over all other treatments (Table 3). Higher urease activity with the application of 100% NPK + FYM might be because of higher organic matter status of soils and the positive correlation between urease activity (Table 4) with organic carbon, SMBC, BSRR and *Azotobacter* and PSM population supported this.

Fluorescein diacetate hydrolyzing activity

The fluorescein hydrolyzing activity (FDHA) in jute rhizosphere increased in all the treatments compared to initial status. Application of 100% NPK with FYM recorded

Table 3 Effect of various fertilizer treatments on enzymatic activities, soil microbial biomass carbon (SMBC) and basic soil respiration rate (BSRR) in jute rhizosphere (three years pooled data at 60 DAS*)

Microbial properties in jute rhizosphere	Treatments						CD	Initial soil
	T_1	T_2	T_3	T_4	T_5	T_6	(*P*=0.05)	status
Dehydrogenase (mg TPF/g oven dry soil/h at 37⁰C)	5.2	5.5	6.3	7.2	6.2	5.9	1.4	3.5
Urease (mg urea hydrolyzed/g oven dry soil/h at 37⁰C)	120.0	132.5	133.4	169.4	152.0	131.8	8.0	130
FDHA (mg fluorescein/g oven dry soil)	180.5	184.7	210.0	236.1	185.7	185.0	7.4	125
Acid phosphatase (mg p-nitro phenol released/g oven dry soil/h at 37⁰C)	147.4	148.8	193.2	228.4	168.9	151.7	6.7	135
Alkaline phosphatase (mg p-nitro phenol released/g oven dry soil/h at 37⁰C)	364.4	453.0	515.1	536.7	455.2	449.5	10.2	350
SMBC(mg C/g oven dry soil)	229.5	239.3	350.5	368.5	360.5	275.5	12.2	180.5
BSRR (mgCO_2-C/g oven dry soil/h at 22⁰C)	0.80	0.90	1.30	1.50	1.00	1.00	0.20	0.80

*The value of microbial properties was maximum at 60 DAS, so the data of only 60 DAS is given in the table

(Table 3) highest FDHA (236.1 mg fluorescein/g soil) which was significantly superior over all treatments. The higher FDHA due to integrated use of NPK and FYM could be attributed to increased microbial biomass resulting from organic matter enrichment and enzymatic activities in soil (Singh and Dhar 2011). A significant and positive correlation between (Table 4) FDHA with organic carbon, SMBC and enzymatic activities also supported this.

Phosphatase activity

The acid and alkaline phosphatase activities (Table 3) were found to increase in jute rhizosphere over the initial status and the highest values of acid phosphatase (228.4 mg p-nitro phenol/g soil) and alkaline phosphatase (536.7 mg p-nitro phenol/g soil) were recorded with 100% NPK + FYM which were significantly superior over all treatments. The increase in phosphatase activity with integrated use of 100% NPK and FYM in soils might be due to the fact that enzyme activities directly associated with organic matter and microbial response to soluble sugars of the added materials (Hojati and Nourbakhsh 2006; Basu *et al*. 2011) which had also been evidenced by the significant and positive correlations between acid and alkaline phosphatase (Table 4) with organic cabon, SMBC, PSM and PSP in soil.

Soil microbial biomass carbon (SMBC)

The combined use of 100% NPK with FYM favoured the build up of microbial biomass carbon (368.5 mg C/g soil) in jute rhizosphere which was significantly superior over all treatments and was at par with 150% NPK (Table 3). Lower microbial biomass carbon in T_1 and T_2 might be because of lesser addition of crop biomass as leaf fall, root decay etc. in the soil while higher status of microbial biomass in T_4 was mainly due to the microbial biomass contained in the FYM and the addition of substrate carbon, which stimulated the indigenous soil micro-biota (Rupela *et al.* 2005, Nath *et al.* 2011). The soil microbial biomass carbon showed significant positive correlation (Table 4) with increased *Azotobacter* and PSM population, organic carbon, BSRR and other enzymatic activities.

Basal soil respiration rate (BSRR)

The basal soil respiration rate decreased significantly with 150% NPK and STCR based recommended dose in

Table 4 Simple correlation between soil enzyme activities and selected soil properties

Parameters	DH activity	Urease	Acid phos-phatase	Alkaline phos-phatase	FDHA	SMBC	BSRR	Organic C	*Azoto-bacter*	PSM	PSP
DH activity	1.000										
Urease	0.704**	1.000									
Acid Phosphatase	0.632**	0.773**	1.000								
Alkaline Phosphatase	0.616**	0.702**	0.839**	1.000							
FDHA	0.587**	0.705**	0.964**	0.834**	1.000						
SMBC	0.594**	0.765**	0.814**	0.788**	0.695**	1.000					
BSRR	0.591**	0.644**	0.871**	0.838**	0.867**	0.744**	1.000				
Organic C	0.660**	0.839**	0.644**	0.587**	0.570*	0.695**	0.566*	1.000			
Azotobacter	0.536*	0.590**	0.708**	0.728**	0.630**	0.687**	0.714**	0.500*	1.000		
PSM	0.534*	0..502*	0.796**	0.827**	0.830**	0.631**	0.773**	0.486*	0.659**	1.000	
PSP	NS	NS	0.673**	0.646**	0.770**	0.470*	0.647**	NS	NS	0.851**	1.000

*P= 0.05, **P=0.01, DH, Dehydrogenase; FDHA, fluorescein diacetate hydrolyzing activity; SMBC, soil microbial biomass carbon; BSRR, basic soil respiration rate; PSM, phosphate solubilizing microorganisms; PSP, phosphate solubilizing power; NS, Non-significant

Table 5 Residual effect of fertilizer treatments on available nutrient status in soil after 3 years of cultivation (at harvest)

Treatments	Organic C	Available N	Available P as P_2O_5 (g/kg)	Available K as K_2O (kg/ha)
T_1	5.6	265	30.5	155.0
T_2	6.0	279	36.2	169.0
T_3	6.1	292	43.0	180.6
T_4	7.7	313	50.0	198.5
T_5	7.1	296	48.0	192.0
T_6	6.2	288	46.0	187.5
CD (*P*= 0.05)	0.9	7.9	5.5	6.7
Initial status	5.8	275	35	170

jute rhizosphere compared to 100% NPK which was because of lower population of various beneficial microbes under these treatments (Table 3). The highest BSRR (1.50 mg CO_2-C/g oven dry soil) in jute rhizosphere was recorded with the integration of 100% NPK + FYM, which was significantly superior over all other treatments as also reported by Manna *et al*. (2005) and Rupela *et al.* (2005). The significant correlation between BSRR (Table 4) with *Azotobacter* and PSM population, SMBC, and enzymatic activities supported the fact.

Residual soil fertility status

The highest content of organic carbon (7.7 g/kg) was recorded with 100% NPK + FYM which was significantly superior over all treatments and was at par with 150% NPK (Table 5) might be because of higher addition of carbon input (Singh and Dhar 2011) as well as higher incorporation of biomass through leaf fall, root exudates and root residues.

Application of 100% NPK + FYM recorded highest content (313 kg/ha) of available nitrogen in soil which was significantly superior over all treatments. There was no significant difference between 100% NPK and 150% NPK indicating the fact that addition of higher doses of N over the recommended dose did not contribute substantially to the available N status. The highest content of available P (50 kg/ha) was recorded in T_4 which was at par with T_5 and T_6 (Table 5). The higher available P in T_4 was due to the efficiency of FYM in increasing the P availability by chelating phosphate fixing cations (Fe^{3+}, Al^{3+} etc.) and reducing phosphate sorption with low bonding energy and exchange of adsorbed PO_4^{3-} by organic anions (Sharma and Tripathi 1999).

The highest available K content (195.5 kg/ha) was recorded with 100% NPK + FYM which was significantly superior over all treatments but was at par with 150% NPK. The higher build up of available K in T_4 could be because of addition of K through FYM, release of more exchangeable K and organic colloids present in FYM enhancing the CEC of the soil which in turn acted as a sink for added K (Kanwar and Parihar 1962).

Thus it can be concluded from the above study that although application of recommended dose of fertilizer (100% NPK) was sufficient for jute fibre production, but integration of recommended dose of fertilizer with 10 t FYM/ha proved to be the best possible option not only for jute fibre production but also for the maintenance of soil microbial health and fertility status and thus sustainability. The microbial properties in jute rhizosphere are maximum at 60 DAS, which happened to be the active growth period for jute crop.

REFERENCES

Alef K. 1995a. Estimation of soil respiration. *Methods in Applied Soil Microbiology and Biochemistry,* pp 215–6. Alef K and Nannipieri P (Eds). Academic Press, London.

Alef K. 1995b. Estimation of FDHA. *Methods in Applied Soil Microbiology and Biochemistry,* pp 232–3. Alef K and Nannipieri P (Eds). Academic Press, London.

Basu M, Bhadoria, P B S and Mahapatra S C. 2011. Influence of soil ameliorants, manures and fertilizers on bacterial populations, enzyme activities, N fixation and P solubilization in Peanut rhizosphere under lateritic soil. *British Microbiology Research Journal* **1**(1): 11–25.

Chandel S R S. 2004. *A Handbook of Agricultural statistics*, pp 281–7. Achal Prakashan Mandir, Kanpur.

Diosma G, Aulicino M, Chidichimo H and Balatti P A. 2006. Effect of tillage and N fertilization on microbial physiological profile of soil cultivated with wheat. *Soil Tillage Research* **91**: 236–43.

Gunapala N, Venette R C, Ferris H and Scow K M. 1998. Effect of soil management history on the rate of organic matter decomposition. *Soil Biology and Biochemistry* **30**: 1 917–27.

Hojati S and Nourbakhsh F. 2006. Enzyme activities and microbial biomass carbon in a soil amended with organic and inorganic fertilizers. *Journal of Agronomy* **5**: 563–9.

Kanwar J S and Parihar S S. 1962. Effect of continuous application of FYM and inorganic fertilizer on the crop yield and properties of soil. *Journal of the Indian Society of Soil Science* **10**: 89–114.

Mandal B. 2005. Assessment and improvement of soil quality and resilience for rainfed production system. *Completion Report National Agricultural Technology Project,* Indian Council of Agricultural Research, New Delhi, pp 30.

Manna M C, Swarup A, Wanjari R H, Ravankar H N, Mishra B, Saha M N, Singh Y V, Sahi D K and Sarap P A. 2005. Long-term effect of fertilizer and manure application on soil organic carbon storage, soil quality and yield sustainability under sub-humid and semi-arid tropical India. *Field Crops Research* **93**: 264–80.

Nath D J, Ozah B, Baruah R, Barooah R C and Borah D K. 2011. Effect of integrated nutrient management on soil enzymes, microbial biomass carbon and bacterial populations under rice (*Oryza sativa*)-wheat (*Triticum aestivum*) sequence. *Indian Journal of Agricultural Sciences* **81** (12): 1 143–8.

Parmer D, and Schmidt E L. 1966. *Experimental Soil Microbiology.* Burges Publication Company, Minneapolis. Minn., USA.

Pikovskaya R I. 1948. Mobilization of phosphate in soil in connection with the vital activities of some microbial species. *Microbiologya* **17**: 362–70.

Rao D L N. 2007. Microbial Diversity, soil health and sustainability. *Journal of the Indian Society of Soil Science* **55**: 392–403.

Rupela O P, Gowda C L L, Wani S P and Bee H. 2005. Evaluation of crop production system based on locally- available biological inputs. (*In*)*Biological Approaches to Sustainable Soil Systems,* pp 501–5. Uphoff N (Ed). CRC Press, Boca Raton, Florida, USA.

Sharma P, Singh G and Singh R P. 2011. Conservation tillage, optimal water and organic nutrient supply enhance soil microbial activities during wheat (*Triticum aestivum* L.) cultivation. *Brazilian Journal of Microbiology* **42**: 528–39.

Sharma U C and Tripathi A K. 1999. Phosphate management in rice-mustard cropping sequence on acid soils of Nagaland. *Journal of the Indian Society of Soil Science* **47**: 732–8.

Singh Y V and Dhar D W. 2011. Changes in soil orgaic carbon and microbial population under organically managed rice (*Oryza sativa*)- wheat (*Triticum aestivum*)- greengram (*Vigna radiata*) cropping system. *Indian Journal of Agricultural Sciences* **81** (4): 363–5.

Tabatabai M A. 1994. Soil enzymes. (*In*) *Methods of Soil Analysis*. Part 2: *Microbial and Biochemical Properties,* pp 198–250. Weaver R W, Angel J S and Bottomley P S (Eds), Soil Science Society America. Madison, WI, USA.

Tandon H L S. 1993. Methods of analysis of soils, plants, water and fertilizers. Fertilizer Development and Consultancy Organization, New Delhi.

Vance E D, Brookes P C, Jenkinson D S. 1987. An extraction method for measuring soil microbial biomass C. *Soil Biology and Biochemistry* **19**: 703–7.