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Effect of Different Jute (*Corchorus olitorius* L.) Based Cropping Systems on Soil Quality under Farmers' Field Condition in the Eastern Indo-Gangetic Plain

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A B S T R A C T

Jute based cropping system is one of the predominant cropping system in Indo-Gangetic plains of Eastern India. Soil quality assessment and identification of key soil indicators are very much important for sustaining high crop yields and maintaining normal functioning of the soil. Soil quality cannot be measured directly but evaluation of individual physical, chemical and biological parameters is the way to study management induced changes in soil quality. The present investigation was carried out to assess the impact of different jute based cropping systems on soil quality in farmers' fields. Soil samples (georeferenced) were collected at 0-0.2 m depth from the farmers' fields following the jute based cropping systems for more than five years. Soil quality was evaluated in terms of physico-chemical and biological attributes of soils. The physico-chemical properties showed considerable variation under jute based cropping systems in three districts. Soils of Hooghly district have much lower organic carbon (6.9 to 9.3 g kg^{-1}) and higher available nitrogen, phosphorus and potassium status as compared to Nadia and North 24-Parganas. Among all jute based cropping systems, jute-rice-potato recorded highest organic carbon (14.1 g kg^{-1}) content followed by jute-rice-lentil (13.2 g kg^{-1}) in North 24 Parganas district and jute-rice-garden pea (12.98 g kg^{-1}) of Nadia district. Soil enzymatic activities, like dehydrogenase (DHA), fluorescein diacetate hydrolyzing (FDHA) and urease activities varied among the cropping systems within each district as well as among the districts. Results indicated that the enzymatic activities and soil microbial biomass carbon were higher in North 24-Parganas and Nadia as compared to Hooghly. Soils of Hooghly district recorded higher acid phosphatase activity in soil while the soils of Nadia and North 24 Parganas recorded higher alkaline phosphatase activity. Jute-rice-potato, jute-rice-coriander and jute-rice-garden pea can safely be recommended for achieving higher soil quality in Hooghly, North24 Parganas and Nadia district, respectively.

Keywords

Jute based cropping system, Soil quality, soil organic carbon, soil microbial biomass, soil enzymes, and farmers' field.

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Introduction

Jute the golden fibre is one of the important cash crops and occupies a prestigious position in the industrial and agricultural economy of India. India earns annually about 2050 corers rupees by exporting various jute products (Satpathy *et al.*, 2014) and more than 4 million farming families depended for their livelihood on jute cultivation. Jute based cropping system is one of the most important cropping systems of the lower Gangetic plain also known as the eastern Indo-Gangetic plain. Jute (*Corchorus olitorius* L.), cash crop of eastern India cultivated in pre-kharif (summer) season followed by rice in kharif (rainy) season and potato, mustard, wheat, pulses and vegetables etc. in the rabi (winter) season utilizing residual moisture or with limited irrigation. Jute-rice-potato, jute-rice-lentil, jute-rice-mustard, jute-rice-garden pea and jute-rice-wheat are some of the important jute based cropping systems followed in the eastern Indo-Gangetic plain. In jute based cropping systems, it has been observed that jute-rice-potato system is showing highest system productivity, energy productivity, net return and economic efficiency (Mukhopadhyaya and Roy, 2000; Kumar *et al.*, 2014). The enzyme activities, microbial biomass carbon and basal soil respiration rate in soil under jute crop reduced significantly after 7 days of herbicides and fungicides application and recovered gradually to the extent of initial level at harvest of the jute crop (Majumdar *et al.*, 2010). Organic manuring and inorganic fertilizer application are the most common agricultural practices. Studies reported that integrated application of recommended doses of fertilizer with 10t FYM/ha was found suitable for sustainable jute fibre production and maintenance of soil microbial health and fertility status in a sandy clay loam soil (Majumdar *et al.*, 2014).

Intensification of cropping system results in higher productivity per unit area per unit time, higher nutrient removal and depletion of the inherent nutrient status of the soil. The poor soil condition can reduce the yield of crops grown later and smallholder farmers will face food insecurity due to severe depletion of nutrients in their soils. Therefore, it is now well established that maintenance of soil quality or soil health is one of the prerequisites for sustainable crop productivity under any cropping system and there is an urgent need to adopt appropriate crop and soil management practice, which can maintain the soil quality at desired level. Studies have shown that management practices like tillage, improved fertilizer management, manuring and compost application, residue incorporation, pesticides application, moisture availability, and presence of salts affects the microbial population and other enzymatic activities in soil (Tripathi *et al.*, 2008, 2008a). Jute based cropping systems with variable crop and nutrient management practices might have affected the soil quality parameters of the soil in successive years.

Over a decade emphasis has been given on soil quality research throughout the world in different crops and cropping systems due to stagnation in yield and declining fertility status of soils. In India, it has also gained importance where the soils are inherently low in soil organic carbon; intensive cultivation has been done with imbalance use of fertilizers and little or no crop residues are returned to the soil. Experiments have been taken into consideration for assessing soil quality on experimental fields with controlled conditions under different cropping systems (Bhaduri and Purakayastha, 2014; Li *et al.*, 2013; Liu *et al.*, 2014; Masto *et al.*, 2007; Mandal *et al.*, 2008) but studies providing an assessment of soil quality under different cropping systems in farmers' fields have remained relatively rare in scientific literature. However they are needed for understanding the options for intensification and diversification of cropping systems helping in maintaining soil quality in Eastern Indo Gangetic plains. The cropping system and management practices that could maintain the soil health/quality will only promote sustainable agriculture i.e., sustain increasing food production in order to meet the demands of the ever increasing population. The present study focuses on long term impact of jute based cropping systems on soil quality in farmers' fields at least five years old of cultivation.

Materials and Methods

Study area

Composite soil samples were collected (0-0.2 m) from important jute based cropping systems of three districts, viz. Hooghly, North 24 Parganas and Nadia districts of West Bengal located in the eastern Indo-Gangetic plain during 3rd week of March, 2014 after harvest of *rabi* (winter) crop. In Hooghly, the annual mean temperature is 26.8ºC, although monthly mean temperatures range from 16 ºC to 33 ºC and maximum temperature in Hooghly often exceeds 38 ºC. The main seasonal influence upon the climate is monsoon. Maximum rainfall occurs during the monsoon in August and the average total annual rainfall is above 1500 mm. In Nadia, the mean annual temperature varies from 10ºC to 40ºC and the annual rainfall ranges from 1250 to 1750 mm. The climate of North 24 Parganas is tropical like rest of the Gangetic West Bengal. The mean annual maximum and minimum temperature of this region is 41ºC and 10ºC. It is also characterized by the monsoon, which lasts from early June to mid-September and the average annual rainfall is 1579 mm. The weather remains dry during winter (mid-Nov to mid-Feb) and humid during summer.

Experimental details and sampling

The samples were drawn from twelve long-term (> 5 years) jute based cropping systems under farmers' field condition. Detailed characterizations of the locations are given in table 1. Jute-rice-potato (J-R-P), jute-rice-onion (J-R-O), jute-rice-ladies finger (J-R-Lf), jute-rice-mustard (J-R-M) cropping systems were selected from Hooghly district, jute-rice-coriander (J-R-Co), jute-rice-potato (J-R-P), jute-rice-mustard (J-R-M) and jute-rice-lentil (J-R-L) from North 24 Parganas district and jute-rice-mustard (J-R-M), jute-rice-lentil (J-R-L), jute-rice-garden pea (J-R-Gp) and jute-rice-wheat (J-R-W) from Nadia district were selected for the study. The information regarding the manures and fertilizers, crop yield and net profit etc. were collected from individual farmer and presented in the table 1. Soil samples were collected from each cropping system after harvesting of jute. Immediately after collection, soil samples were brought to the laboratory and stored in a refrigerator for measurement of biological attributes of soil. A subset of soil samples was air-dried and passed through a 2 mm sieve for determination of physico-chemical properties.

Methods of analysis

The attributes of soil quality viz. pH of soil in water (pHw) (1:2.5:: w:v) (Page *et al.*,1982), easily oxidisable organic carbon (OC) (Walkey and Black,1934), available nitrogen (Subbiah and Asija, 1956), available P (Olsen' *et al.*,1954), available potassium was extracted with neutral 1N ammonium acetate (NH_4OAc-K) (Hanway and Heidel, 1952) were determined.

Refrigerated soil samples were used immediately for assessing a number of biological properties. The population of phosphate solubilizing bacteria were estimated following serial dilution technique and pour plate method (Parmer and Schmidt, 1966) using Pikovskaya's agar media (Pikovskaya, 1948). One gm of each soil samples were incubated separately at 30±1^{0}C for 15 days in 15 ml Pikovskaya's broth with 15 g insoluble phosphate and then soluble P in the broth were estimated for determination of phosphate solubilizing capacity of soil samples. The soil samples were analysed for dehydrogenase, urease, acid and alkaline phosphatase enzymatic activities by the methods of Tabatabai (1994) and fluorescein diacetate hydrolysing activity (FDHA) by the method of Alef (1995). The microbial biomass carbon of soil samples (SMBC) were estimated by chloroform fumigation extraction method of Vance *et al.,* (1987). For statistical analysis of data Microsoft Excel and SPSS window version 12.0 package was used.

Results and Discussion

Physico-chemical properties of soil

The data presented in table 2 indicated that the soils of Hooghly district (S1 to S4) under different jute based cropping systems were slightly acidic to neutral in nature (5.6 to 6.9), while the soils of North 24 Parganas (S5 to S8) and Nadia (S9 to S12) districts were neutral to slightly alkaline in nature. The pH value of 5.6 in S1 under jute-rice-potato cropping system in Hooghly district might be because of higher use of inorganic fertilizer especially muriate of potash, which helped in the lowering of soil pH after release of Cl ions in soil solution. On the other hand, application of recommended doses of fertilizer helped in maintaining the soil pH in the range of 7 to 7.5 in most of the soils of Nadia and North 24 Parganas districts under jute based cropping system.

The organic carbon content of the soils showed considerable variation under various jute based cropping systems in three districts. Hooghly district soils have much lower organic carbon (6.9 to 9.3 g/kg) compared to North 24Parganas (9.3 to 14.1 g/kg) and Nadia (9.9 to 12.9 g/kg) districts (Table 2). Jute-rice-potato (S1) and jute-rice-mustard (S4) cropping systems in Hooghly districts received considerable organic matter with inorganic fertilizer, which has resulted in higher organic carbon content in both the cropping systems compared to other two cropping systems which did not receive any organic manure. This is in agreement with the findings of Majumdar *et al.,* (2014) who have reported higher organic carbon build up with the application of FYM in combination with inorganic fertilizer. In contrast, balanced fertilizer use also helped in build-up of higher organic carbon status in the soils of Nadia and North 24 Parganas districts under various jute based cropping systems. Among all jute based cropping systems, jute-rice-potato (S6) recorded highest organic carbon (14.1 g/kg) content followed by jute-rice-lentil (13.2 g/kg) in North 24 Parganas district and jute-rice-garden pea (12.9 g/kg) of Nadia district. This might be due to greater rhizodeposition and leaf shedding of jute throughout its growth period and incorporation of potato haulm at harvest, both resulting an increase in organic carbon. In addition, increased organic carbon content in cropping sequences involving lentil, vegetable pea might be due to addition of nutrient by biological N-fixation by these crops. Pulses or food legumes add a significant amount of organic carbon to soil because of their ability for atmospheric nitrogen fixation, leaf shedding ability and greater below ground biomass (Ganeshamurthy, 2009). Higher organic carbon content in jute-potato was also reported by Biswas *et al.,* (2006).

The soils of Hooghly district recorded higher available N, P and K status compared to Nadia and North 24 Parganas districts under various jute based cropping systems (Table 2). There was variation in available N, P and K content under different cropping systems within each district indicating the fact that the cropping sequences and fertilizer and manure use have affected the nutrient build up pattern in the soil. The available N status ranged between 300 (jute-rice-onion) to 385 kg/ha (jute-rice-mustard) in Hooghly district, 282 kg (jute-rice-mustard) to 323.4 kg/ha (jute-rice-potato) in North 24 Parganas district and 260 (jute-rice-wheat) to 290.4 kg/ha (jute-rice-mustard) in Nadia district. The soils of Hooghly district recorded very high available P (148.4 to 188.4 kg/ha) with a mean of 170.25 kg/ha compared to North 24 Parganas (22.2 to 126.7 kg/ha) with a mean of 85.6 kg/ha and Nadia district (27.3 to 93.9 kg/ha) with a mean of 52.1 kg/ha. The available K status also follows the same trend as that of available N and P.

The higher available N, P and K status in Hooghly district may be because of higher application of N, P and K fertilizers under different cropping systems, besides that Hooghly district being traditionally potato growing area, farmers apply higher doses of N, P and K for maximization of yield, so soils are inherently rich in various plant nutrients which might have contributed to the higher N, P and K status in soil.

Enzymatic properties of soil

Soil enzyme activities and microbial biomass are affected by different management practices and can be used as indicators of soil quality. Soil enzymes are important soil components that play an essential role in catalysing reactions necessary for organic matter decomposition and nutrient cycling. Microbial biomass is the labile portion of the organic fraction in soils and serves as both an important source of and sink for plant available nutrients (Jenkinson and Ladd, 1981; Garcia and Rice, 1994).

Dehydrogenase activity

Dehydrogenase activity is a measure of the intensity of microbial metabolism and in turn, the microbial activity in soil. The dehydrogenase activities in the soil under different jute based cropping systems were higher in North 24 Parganas and Nadia districts compared to Hooghly district (Table 3). The dehydrogenase activity in the Hooghly district ranged between 2.1 to 4 with a mean of 3.45 mg TPF/g oven dry soil, whereas in North 24 Parganas district, the dehydrogenase activity ranged between 3.9 to 5.6 with a mean of 4.75 mg TPF/g oven dry soil and in Nadia district, the same ranged between 5 to 6.2 with a mean of 5.5 mg TPF/g oven dry soil. Among all the jute based cropping systems under study, jute-rice-garden pea in Nadia district recorded highest dehydrogenase activity (6.2 mg TPF/g oven dry soil) followed by jute-rice-lentil (5.6 mg TPF/g oven dry soil) and jute-rice-potato (5.6 mg TPF/g oven dry soil) respectively in Nadia and North 24 Parganas district. The higher dehydrogenase activity in the soils under different jute based cropping systems was directly associated with organic carbon build up in the soil. This could be due to the result of higher concentration of labile C substrates in these soils. The same has also been reported by Majumdar *et al.,* (2014) in jute crop.

Urease activity

The urease activities in the soils under different jute based cropping systems are presented in table 3 which varied among the cropping systems within each district as well as among the districts.

The soils of Hooghly district recorded lower urease activities under different jute based cropping systems compared to the soils of Nadia and North 24 Parganas districts. The urease activity in Hooghly district ranged between 113.8 to 140.3 with a mean of 132.8 mg urea hydrolysed/g oven dry soil, whereas in North 24 Parganas district, the urease activity was in a range between 113.8 to

170.4 with a mean of 143.1 mg urea hydrolysed/g oven dry soil and in Nadia district, the same ranged between 124.4 to 153.6 with a mean of 137 mg urea hydrolysed/ g oven dry soil. Among the cropping systems, jute-rice-coriander of North 24 Parganas district recorded maximum urease activity (170.4 mg urea hydrolysed/ g oven dry soil) which received 110 kg N/ha/yr through urea and 18 t/ha/yr of organic manure through farm yard manure, mustard cake and poultry manure. Higher urease activity in soil under jute crop with 100% NPK + FYM over 150% NPK was also reported by Majumdar *et al.*, (2014). From the urease activity data, it is clear that, the soil which received higher applied inorganic N fertilizer recorded lower urease activity compared to balanced/ recommended application of nitrogenous fertilizer.

Table.1 Details of soil samples collected under various jute based cropping system

Sample No.	Location	Cropping sequence	Fertilizer used (kg/ha)				Manure used (q/ha)	Fertilizer source	Crop yield (q/ha)	Net profit (Rs./ha)
			N	P as P_2O_5	K as K_2O	S as SO_4				
S1	Goribati, Hooghly	Jute-Rice-Potato	310	230	330	20	M. cake (4.25)	Urea, DAP, Gromore and MOP	431.25	1,37,000
S2	Beraberi, Singur, Hooghly	Jute-Rice-Onion	241	231	231	--	--	Urea, Gromore and MOP	285	1,05,000
S3	Beraberi, Singur, Hooghly	Jute-Rice-Ladiesfinger	276	252	252	--	M. cake (2.80)	Urea, Gromore and MOP	302	1,47,000
S4	Bachipota, Singur, Hooghly	Jute-Rice-Mustard	235	200	200	--	V. compost (3.75) + Dhaincha (15)	Urea, Mixed NPK (10:26:26)	117	87,000
S5	Atghara, North 24 Parganas	Jute-Rice-Coriander	110	--	40	--	FYM (100) + M. cake (3) + Poultry manure (77)	Urea, MOP	114	97,000
S6	Goaldah, North 24 Parganas	Jute-Rice-potato	330	150	200	25	--	Urea, SSP, MOP and elemental S	274	1,23,000
S7	Goaldah, North 24 Parganas	Jute-Rice-Mustard	240	120	120	--	--	Urea, Mixed NPK (10:26:26)	105	69,000
S8	Goaldah, North 24 Parganas	Jute-Rice-Lentil	180	140	120	40	--	Urea, SSP, MOP and elemental S	112	80,000
S9	Panchkahonia, Nadia	Jute-Rice-Mustard	240	120	120	--	--	Urea, Mixed NPK (10:26:26)	105	69,000
S10	Panchkahonia, Nadia	Jute-Rice-Lentil	180	140	120	--	--	Urea, MOP and Mixed NPK (10:26:26)	100	63,000
S11	Panchkahonia, Nadia	Jute-Rice-Pea	200	140	120	--	--	Urea, MOP and Mixed NPK (10:26:26)	152	1,14,000
S12	Gopalpur, Karimpur, Nadia	Jute-Rice-Wheat	280	140	120	--	--	Urea, MOP and Mixed NPK (15:15:15)	127	62,000

Table.2 Effect of different jute based cropping system on physico-chemical properties of soil

			Available nutrients (kg/ha)		
Sample No.	**pH (1: 2.5)**	**Organic C (g/kg)**	**N**	**P**	**K**
S1 (J-R-P)	5.6 ± 0.12e	9.3 ± 0.21ef	308.0 ± 0.88d	188.4 ± 1.09a	341.5 ± 0.97c
S2 ((J-R-O)	6.5 ± 0.12cd	8.7 ± 0.24f	300.0 ± 0.93e	167.3 ± 0.92c	355.0 ± 0.90a
S3 (J- R-Lf)	6.9 ± 0.15bcd	6.9 ± 0.17g	338.8 ± 1.18b	148.4 ± 0.92d	335.0 ± 0.87d
S4 (J-R-M)	6.5 ± 0.12cd	9.0 ± 0.15f	385.0 ± 0.93a	176.9 ± 1.09b	340.5 ± 0.83c
S5 (J-R-Co)	6.4 ± 0.12d	10.5 ± 0.13cd	297.4 ± 0.92e	126.7 ± 1.08e	348.5 ± 1.07b
S6 (J-R-P)	7.2 ± 0.12ab	14.1 ± 0.19a	323.4 ± 1.09c	99.2 ± 0.92f	278.0 ± 0.87g
S7 (J-R-M)	7.5 ± 0.09a	9.3 ± 0.28ef	282.0 ± 1.01g	22.2 ± 0.85k	252.3 ± 0.94h
S8 (J-R-L)	7.1 ± 0.07ab	13.2 ± 0.23ab	310.2 ± 0.75d	94.2 ± 0.83g	228.0 ± 1.04i
S9 (J-R-M)	7.0 ± 0.10abc	11.4 ± 0.19c	290.4 ± 0.78f	93.9 ± 0.84g	326.5 ± 1.17e
S10 (J-R-L)	7.3 ± 0.07ab	12.6 ± 0.2b	277.2 ± 0.85h	33.2 ± 0.58i	249.6 ± 0.76h
S11 (J-R-Gp)	6.9 ± 0.10bcd	12.9 ± 0.19b	285.0 ± 0.93g	54.0 ± 0.76h	230.7 ± 0.80i
S12 (J-R-W)	7.2 ± 0.12ab	9.9 ± 0.10de	260.0 ± 1.11i	27.3 ± 0.84j	288.4 ± 0.67f

Table.3 Effect of different jute based cropping system on enzymatic activities of soil

Sample No.	**Dehydrogenase (mg TPF/g oven dry soil/hr at 37^{0}C)**	**Urease (mg urea hydrolysed/g oven dry soil/hr at 37^{0}C)**	**Fluorescein diacetate hydrolysing activity (mg fluorescein/g oven dry soil)**	**Phosphatase activity (mg p-nitro phenol released/g oven dry soil/hr at 37^{0}C)**	
				Acid phosphatase	**Alkaline phosphatase**
S1 (J-R-P)	2.1 ± 0.09g	113.8 ± 0.81f	104.8 ± 0.76g	252.6 ± 0.92a	136.7 ± 0.62k
S2 ((J-R-O)	3.8 ± 0.12f	139.5 ± 0.90c	114.3 ± 0.74abc	193.2 ± 0.78c	226.6 ± 0.98i
S3 (J- R-Lf)	3.9 ± 0.12f	137.6 ± 1.01cd	104.9 ± 0.82g	103.2 ± 0.68k	116.2 ± 0.78l
S4 (J-R-M)	4.0 ± 0.09ef	140.3 ± 0.85c	105.8 ± 0.69fg	190.4±0.76c	176.7 ± 1.01j
S5 (J-R-Co)	4.5 ± 0.12de	170.4 ± 0.84a	118.0 ± 0.74a	215.8 ± 0.93b	342.1 ± 0.75e
S6 (J-R-P)	5.6 ± 0.12b	113.8 ± 0.84f	115.8 ± 0.87abc	124.9 ± 0.76j	394.0 ± 0.60b
S7 (J-R-M)	5.0 ± 0.12cd	138.2 ± 0.75c	108.6 ± 0.80efg	160.8 ± 0.74f	283.4 ± 0.67h
S8 (J-R-L)	3.9 ± 0.12f	150.1 ± 0.91b	113.5 ± 0.73bcd	131.4 ± 0.64i	383.4 ± 0.66c
S9 (J-R-M)	5.0 ± 0.09cd	133.4 ± 0.72d	112 ± 0.90cde	139.9 ± 0.78h	314.4 ± 0.71g
S10 (J-R-L)	5.6 ± 0.12b	153.6 ± 0.58b	109.5 ± 0.78def	156.2 ± 0.68g	328.3 ± 0.76f
S11 (J-R-Gp)	6.2 ± 0.10a	124.4 ± 0.72e	115.5 ± 0.88abc	172.6 ± 0.74d	352.1 ± 0.78d
S12 (J-R-W)	5.2 ± 0.12bc	136.7 ± 0.79cd	116.3 ± 0.47ab	165.8 ± 0.65e	432.8 ± 0.83a

Table.4 Effect of different jute based cropping system on PSB population, phosphate solubilizing capacity and microbial biomass carbon in soil

Sample No.	**Phosphate solubilizing bacteria(CFUx10^5/g dry weight of soil)**	**Phosphate solubilizing capacity (ppm)**	**Soil microbial biomass carbon (mg C/g oven dry soil)**
S1 (J-R-P)	11.0 ± 0.07a	3.42 ± 0.001a	295.1 ± 1.19f
S2 ((J-R-O)	7.3 ± 0.07c	2.67 ± 0.001g	191.0 ± 0.97i
S3 (J- R-Lf)	10.7 ± 0.12a	3.33 ± 0.001b	194.3 ± 0.97i
S4 (J-R-M)	3.5 ± 0.10f	2.98 ± 0.001f	281.1 ± 0.92g
S5 (J-R-Co)	6.0 ± 0.06d	2.09 ± 0.001j	590.3 ± 0.84a
S6 (J-R-P)	3.7 ± 0.06f	2.54 ± 0.001h	281.1 ± 0.73g
S7 (J-R-M)	6.0 ± 0.12d	3.15 ± 0.001d	342.2 ± 0.75e
S8 (J-R-L)	5.7 ± 0.10d	3.22 ± 0.001c	408.8 ± 0.81c
S9 (J-R-M)	9.4 ± 0.10b	2.40 ± 0.001i	277.8 ± 0.84g
S10 (J-R-L)	7.1 ± 0.12c	2.97 ± 0.001f	366.6 ± 1.01d
S11 (J-R-Gp)	4.5 ± 0.09f	2.97 ± 0.001f	452.3 ± 0.75b
S12 (J-R-W)	9.3 ± 0.10b	3.09 ± 0.001e	271.4 ± 0.59h

Fluorescein diacetate hydrolysing activity

The fluorescein diacetate hydrolysing activity was higher in the soils of North 24 paraganas and Nadia districts compared to Hooghly district (Table 3) under various jute based cropping systems. The FDHA in Hooghly district ranged between 104.8 to 114.3 with a mean of 107.45 mg fluorescein/g oven dry soil, whereas in the soils of North 24 Parganas, it ranged between 108.6 to 118 with a mean of 113.97 mg fluorescein/g oven dry soil and in Nadia district, it ranged between 109.5 to 116.3 with a mean of 113.3 mg fluorescein/g oven dry soil.

The maximum FDHA (118 mg fluorescein/g oven dry soil) was recorded in jute-rice-coriander cropping system in North 24 Parganas district followed by jute-rice-wheat (116.3 mg fluorescein/g oven dry soil) cropping system in Nadia district. The higher FDHA in jute-rice-coriander cropping system in North 24 Parganas district receiving a combination of inorganic N (100 kg/ha/yr) and organic manure (18 t/ha/yr) might have provided a better substrate and nutrient cycling capacity compared to other systems which in turn reflected in the higher FDHA in the system.

This was also supported by the findings of Diallo-Diagne *et al.,* (2016). The higher FDHA in Nadia and North 24 Parganas districts compared to Hooghly district might be because of increased microbial biomass carbon resulting from organic matter enrichment and enzymatic activities in soil (Singh and Dhar, 2011) following use of recommended doses of fertilizer in various jute based cropping systems. This was also supported by the findings of Majumdar *et al.,* (2014), who reported increment in FDHA, organic carbon and microbial biomass carbon content in soil with integrated use of 100 % NPK and farm yard manure in jute crop.

Phosphatase activity

The data on acid and alkaline phosphatase activity presented in table 3 indicated that the soils of Hooghly district recorded higher acid phosphatase activity in soil compared to North 24 Parganas and Nadia district, while the soils of Nadia and North 24 Parganas districts recorded more than 2 folds alkaline phosphatase activities compared to Hooghly district. The jute-rice-potato cropping system in Hooghly district recorded maximum acid phosphatase activity (252.6 mg p-nitro phenol/g oven dry soil) followed by jute-rice-coriander cropping system (215.8 mg p-nitro phenol/g oven dry soil) in North 24 Parganas district, interestingly both the systems had soil pH of 5.6 and 6.4 respectively. Optimum soil pH for acid phosphatase activity is 4 to 6.5 (Dick and Tabatabai, 1984; Wittmann *et al.,* 2004). Hence the higher acid phosphatase activity in these two systems as well as in general, in the soils of Hooghly district under jute based cropping system is justified. The finding is also supported by the findings of Sarapatka *et al.,* (2004) who reported negative correlation between acid phosphatase activities with increasing pH under cereal crops. So, the higher alkaline phosphatase activities in North 24 Parganas and Nadia districts compared to Hooghly district might be because of higher soil pH which has helped in the increasing alkaline phosphatase activity.

Further, application of nitrogen fertilizer has also affected the acid and alkaline phosphatase activity in the soil of jute based cropping systems under study in three districts. The soils of Hooghly district under jute based cropping system received 265.5 kg N/ha/yr compared to 215 and 225 kg/ha/yr respectively by North 24 Parganas and Nadia districts. Higher N application resulted in reduction of alkaline phosphatase activity and increase in acid phosphatase activity. Hence, the soils of Hooghly district recorded very low alkaline phosphatase and very high acid phosphatase activity in the soil. Higher acid phosphatase activity may be because of the fact that phosphomonoesterases are the enzymes most sensitive to changes in soil pH. Increase in acid phosphatase and decrease in alkaline phosphatase activity with higher N application was also reported by Lemanowiez (2011).

Phosphate solubilizing bacteria and phosphate solubilizing capacity

The phosphate solubilizing bacterial population and phosphate solubilizing capacity of jute based cropping systems in three districts are presented in table 4. The phosphate solubilizing bacterial population was higher in the soils of Hooghly district followed by Nadia and North 24 Parganas districts. The phosphate solubilizing capacity of soils in jute based cropping systems followed the same trend as that of phosphate solubilizing bacteria in three districts. Among all the cropping systems, jute-rice-potato in Hooghly district recorded highest population of phosphate solubilizing bacteria (11x 10^5 cfu/g oven dry soil) and phosphate solubilizing capacity (3.42 ppm) followed by jute-rice-ladies finger of Hooghly district, which recorded phosphate solubilizing bacterial population of 10.7 x 10^5 cfu/g oven dry soil and phosphate solubilizing capacity of 3.33 ppm. The higher growth and activity of phosphate solubilizing bacteria as well as high acid phosphatase activity affected greater solubilisation of insoluble inorganic phosphate compounds and mineralization of organic P, which in turn enhanced the available P status in jute-rice-potato and jute-rice-ladies finger cropping system in particular and Hooghly district as a whole compared to Nadia and North 24 Parganas districts. This is also supported by the findings of Das and Debnath, (2006), Majumdar *et al.,* (2010) and Das *et al.*, (2012).

Soil microbial biomass carbon (SMBC)

The soil microbial biomass carbon showed a wide variation among the jute based cropping system of three districts (Table 4). The soils of Hooghly district recorded lower microbial biomass carbon content compared to Nadia and North 24 Parganas districts like organic carbon content. Among the jute based cropping systems, jute-rice-coriander cropping system of North 24 Parganas district recorded the highest soil microbial biomass carbon (590.3 mg C/g oven dry soil) as well as higher organic carbon content of 10.5 g/kg. The higher soil microbial biomass carbon content in the soils of North 24 Parganas and Nadia districts compared to Hooghly district may be because of higher organic carbon and enzymatic activities in the soils of these two districts. This was also supported by the findings of Tabatabai (1997), Frankenberger and Dick (1983), who reported that enzymatic activities and microbial biomass are closely related because transformation of the important organic element occur through microorganisms. The significant and positive correlation among soil microbial biomass carbon, organic carbon and enzymatic activities were also reported by Majumdar *et al.,* (2014).

Results showed that the studied soil physico-chemical and biological attributes in farmers' fields under different jute based cropping systems showed considerable variation in three districts of West Bengal. The overall results indicated that the soil organic carbon, enzymatic activities and soil microbial biomass carbon were higher in North 24-Parganas and Nadia as compared to Hooghly. Jute-rice-potato, jute-rice-coriander and jute-rice-gardenpea maintain higher soil quality and economically beneficial for sustainable crop production. These recommendations will help the farmers in maintaining soil quality and yield sustainability by employing optimum management practices in jute based cropping systems in the Eastern Indo-Gangetic plain

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