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Energy saving in relation to soil carbon pools and enzymatic activities under different conservation tillages and nutrient management in tropical rice

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ABSTRACT

Soil energy saving, net carbon gain, soil organic carbon (SOC) pools, soil enzymatic activities and yield were quantified under five RCTs in two rice grown seasons at four crop growth stages. The treatments included conventional practice as control (CC), zero tillage (ZT), dry drill seeded rice with paired row *dhaincha* (DDS), biochar application (BC) and residue retention and incorporation (RT). SOC pools (microbial biomass carbon, readily mineralizable carbon) and soil enzymatic activities (dehydrogenase, fluorescein di-acetate, urease, β-glucosidase, phosphatase) were studied at active tillering, maximum tillering, panicle initiation and grain filling stages of rice. The energy ratio was highest in ZT practices for both the seasons, however, the net carbon gains were 6.9% and 16.6% higher in RT treatment over CC during *kharif* and *rabi* seasons, respectively. Grain yield was also 5.9% and 7.6% more in RT treatment than CC in the two seasons, respectively. There were yield reduction of 18.7% and 2.1% in ZT than CC for two consecutive wet and dry seasons, respectively, but at the same time energy input was lowest in ZT. The soil labile carbon pools as well as enzymatic activities were significantly higher at PI stage of crop growth and were significantly higher under RCTs over conventional control, which signified improvement of soil quality. Therefore, we can conclude that from environmental sustainability point of view, ZT and residue retention / incorporation could be the options to conserve soil carbon and health with initial marginal yield loss in rice-rice cropping system in tropical lowland having heavy textured soil in eastern India.

1. INTRODUCTION

Resource conservation technologies (RCTs) are set of agriculture practices, including agronomic practices and mechanization, that save resources *viz.,* inputs, labor, energy etc. sustain yield, and conserve natural resources. In RCTs for rice, the conservation tillage practices of rice are combined with residue retention along with zero / minimum tillage for preventing soil erosion and maintaining soil health. Extensive tillage accelerates mineralization of organic matter and destroys the habitat of the soil life. Under zero tillage (ZT) condition, the mineralization of soil organic matter (SOM) can be reduced to levels inferior to the input, converting the soil into a carbon sink (Bhattacharyya *et al.,* 2014; Dash *et al.,* 2017). ZT also results in water saving and improved water use efficiency (WUE) (Das *et al.,* 2016; Parihar *et al.,* 2017). Intensive tillage reduces soil organic carbon (SOC) stock, which is one of the important indicators of soil health assessment (Naresh *et al.,* 2015). Tillage, cropping sequence and residues management have significant impact on soil microbial activity and decomposition processes that transform the plant-derived C to SOM and CO_2 emission by changing the soil environment *viz.,* soil moisture, soil temperature, soil labile C pools, soil biological activities (soil enzymatic activities and microbial population), soil pH, and soil aeration (Amos *et al.,* 2005; Jagadamma *et al.,* 2010).

Soil organic C is the most important factor in maintaining soil fertility, sustaining the productivity of agro-ecosystems, and playing a key role in global C cycling (Su *et al.,* 2006). Soil micro-organisms play an important role in the release of CO_2 by decomposition of SOM, which is the single major component limiting the amount of available energy, thereby affecting the soil microbial diversity (Vance and Chapin 2001; Fontaine *et al.,* 2003).

Maintenance of soil structure is an important feature of sustainable agriculture because it impacts a range of soil processes, including water holding capacity, soil aggregation and physical support to plant roots, hence influencing crop yield. Soil enzymes play a pivotal role in controlling the decomposition of SOM and have been widely accepted as indicators of changes in below ground processes (Sinsabaugh *et al.,* 2002). Soil enzymes are the key features of functional microbial diversity in soil, including rice soil. The enzymes dehydrogenase and fluorescein di-acetate (FDA) depict the biological activity of soil microorganisms in terms of soil respiration. On the other hand, the enzyme β-glucosidase is a C-dependent enzyme and indicates the C substrate utilization by microorganisms (Bhattacharyya *et al.,* 2012a; 2013). Soil enzyme activities, soil labile carbon pools and microbial populations were strongly influenced by the RCTs like zero/ minimum tillage, residue retention, green manuring, soil amendment (biochar) etc. Considering the above mentioned facts, a study was planned with following objectives (1) to study the effect of RCTs on soil C pools in rice; (2) to study soil enzymatic activities and microbial population dynamics under different RCTs; and, (3) to study the energy balance of different RCTs in lowland rice ecologies.

2. MATERIALS AND METHODS

Site Description

The study site was the experimental field of ICAR-National Rice Research Institute, Cuttack, in the Eastern part of India. Climate of the region is tropical with mean annual precipitation of around 1500 mm, out of which 75-80% is generally received between June to October. The soil is an Aeric Endoaquept (USDA, 1999) with sandy clay loam texture. Total C and N content of initial soil was 0.79 and 0.077%, respectively.

Crop Establishment

The field experiment was carried out in *kharif* 2014 (July-Oct) followed by *rabi* 2015 (Jan-April) in rice-rice cropping system. The crop duration was 120 days (*c.v.* Naveen). The critical physiological growth stages considered were active tillering, maximum tillering, panicle initiation and grain filling. Five treatments imposed in a randomized block design experimental plot with four (4) replications; *viz*, T1 - (conventional control), T2 - (zero tillage), T3 - (paired row rice + *dhaincha*, *Sesbania aculeate*), T4 - (biochar application) and T5 - (rice straw retention and incorporation). Rice plants (*c.v.* Naveen, photoperiod non-sensitive) were transplanted at a spacing of 20 cm ×15 cm with one-two seedlings per hill. In all the experimental plots, nitrogen (N) fertilizer was applied in the form of urea @ 80 kg ha^{-1} whereas; in T3 and T5 treatments, 75% of recommended N was applied in 3 split doses, *i.e.* 50% basal application, 25% @ first top dressing and 25% at PI stage.

Sample Collection and Processing

Individual soil samples were collected from rows in between the plants at four crop growth stages of rice with a sample probe augur from 0-15 depths. After collection, excess water was drained off, root fragments and gravels were removed manually and kept in the laboratory for analyses. Moisture content of individual samples was determined gravimetrically in 10 g soils after drying at 105°C till a constant weight was attained. A proportion of fresh soil samples were kept in the refrigerator at 4°C for soil enzymatic and microbial analyses. Another part of fresh soil was air-dried (in shades) for 7-9 days, sieved through a 2 mm mesh, and mixed and stored in sealed plastic jars for analyses of soil carbon pools (Bhattacharyya *et al.,* 2012a, 2013).

Yield

Grain yield was expressed as Mg ha^{-1}. The harvest index was determined by the following formula:

$$\text{Harvest Index (\%)} = \frac{\text{Grain Yield}}{(\text{Grain Yield + Straw Yield})} \times 100 \qquad ...(1)$$

Energy Ratio

Total input and output energy for all the agriculture operations were estimated for each treatment. All the agricultural operations including sowing, weeding, fertilizer applications, inputs such as rice and *dhaincha* seeds, fertilizers, harvesting as per the treatments were considered as components for total input energy (E_I) (Table 1). On the other hand, grain yield, straw yield and husk yield were considered as components for total output energy (E_O) (Sartori *et al.,* 2005). The energy ratio was calculated by the following equation:

$$\text{Energy ratio} = \frac{E_I}{E_O} \qquad ...(2)$$

Soil Carbon Pools

Soil microbial biomass carbon (MBC) was estimated by modified chloroform fumigation–extraction method with fumigation at atmospheric pressure (Witt *et al.,* 2000). Readily mineralizable carbon (RMC) content of the soil samples was estimated after extraction with 0.5 M K_2SO_4 (Inubushi *et al.,* 1991) followed by wet digestion of the soil extract with dichromate (Vance *et al.,* 1987). Oxidizable organic carbon (OC) was estimated by dichromate wet digestion of the dry soils (Walkley and Black, 1934).

Soil Enzymatic Activities

Soil dehydrogenase (DHA) activity was determined by reduction of 2,3,5 – triphenyl tetrazolium chloride (TTC) (Casida *et al.,* 1964). FDA hydrolysis activities were estimated by following the method given by Adam and

Table: 1
Estimated input and output energy for different agriculture activities under different treatments of the study

Operations	Fuel energy (MJ ha^{-1})	Human energy (MJ ha^{-1})	Machine energy (MJ ha^{-1})	Total energy requirement (MJ ha^{-1})
Input energy components				
Preparatory tillage with Power tiller	1573.8	42.1	48.7	1664.7
Puddling with power tiller	1351.4	31.4	36.3	1419.1
Weeding with Cono-weeder	-	215.6	19.2	234.7
Weeding -manually	-	548.8	-	548.8
Sowing with three row manual seed drill	-	35.3	13.2	48.5
Weeding with Cono-weeder	-	215.6	19.2	234.7
Manual sowing	-	176.4	-	176.4
Manual weeding	-	705.6	-	705.6
Sowing with CRRI drum seeder	-	43.1	20.7	63.8
Irrigation	-	109.7	1112.5	1222.2
Fertilizer application manually in treatments	-	31.4	-	31.4
Energy for chemical fertilizer	-	-	-	5560
Energy for herbicide	-	-	-	59.5
Energy for pesticide	-	-	-	2661.6
Manual harvesting	-	-	-	432.3
Energy of reaper for harvesting	-	-	-	117.9
Bundling of rice straws with grain	-	-	-	115
Energy for thresher for grain processing	-	-	-	38.8
Output energy components (MJ ka^{-1})				
Energy for grain yield	-	-	-	14.7
Energy for straw yield	-	-	-	12.5
Energy for husk	-	-	-	13.8

(Source: Sartori et al., 2005; Chaudhary et al., 2006; Sharda et al., 2019)

Duncan (2001). The β-glucosidase (β-GLU) activity was assayed by following the procedure recommended by Eivazi and Tabatabai (1988). Urease activity was estimated by the method of Tabatabai and Bremner (1972). The acid and alkaline phosphatase activity was estimated by the protocol as given by Eivazi and Tabatabai (1977).

Statistical Analysis

Individual parameters were analyzed by analysis of variance (ANOVA) and means were separated by Turkey-Kramer' HSD test at 0.05 level of probability using statistical software SPSS 20.0 (Statistical Package for Social Science).

3. RESULTS AND DISCUSSION

Yield

In *kharif* season 2014, among the different treatments, grain yield varied from 3.9-5.1 Mg ha^{-1} and maximum grain yield was observed in the residue retention and incorporation (RT) treatment (Table 2). The order of grain yield was RT > DDS = BC > CC > ZT. On similar line, grain yield varied from 4.9-5.1 Mg ha^{-1} among the different RCTs in the *rabi* season 2014 and maximum yield was found in RT treatment, but was at par with DDS and the lowest yield was observed in ZT treatment for both the seasons (Table 2).

Energy Ratio

In *kharif* season, energy input, output energy and energy ratio varied in the range of 17.4 - 26.3 GJ ha^{-1}, 151-174 GJ ha^{-1} and 6.4-8.7, respectively among the different RCTs (Table 3). Input energy was significantly less under ZT (17.4 GJ ha^{-1}), whereas, it was found highest in RT. Output energy was found highest in DDS, whereas, the net C gain was found numerically more in RT and DDS, but at par with BC treatment (Table 3). In *rabi* season, inputs and output energy and energy ratio ranged from 16.3-30.72 GJ ha^{-1}, 132-226 GJ ha^{-1} and 5.9-12.36, respectively among the different RCTs (Table 3). Here also input energy was significantly less under ZT (16.16 GJ ha^{-1}), whereas, output

Table: 2
Grain yield and harvest index of rice crop (*cv.* Naveen) under different resource conservation treatments during *kharif* and *rabi* seasons of 2014-2015

Treatments	*Kharif* season		*Rabi* season	
	Grain yield (Mg ha^{-1})	Harvest index (%)	Grain yield (Mg ha^{-1})	Harvest index (%)
CC	4.8b	40.4ab	4.8ab	40.3a
ZT	3.9a	39.6a	4.7a	39.8a
DDS	5.0c	42.9b	5.2c	41.9b
BC	5.0c	42.0ab	5.1bc	43.0b
RT	5.1d	43.2b	5.2c	43.2b

CC: conventional control; ZT: Zero tillage; DDS: dry direct seeded (with paired row dhaincha); BC: biochar and RT: residue retention and incorporation. In each column, means followed by common letter are not significantly different (p < 0.05) by Tukey–Kramers' HSD test in a given year and plant growth stages.

energy was found highest in biochar treatment. Like *kharif* season, the net C grain was also found highest in residue retention technique, which was at par with biochar treatment (Table 3).

Soil Carbon Pools

The labile soil carbon pools like MBC and RMC varied significantly among the treatments in the *kharif* season 2014. The MBC content varied in the range of 287-477 mg kg^{-1} among the different RCT treatments throughout the crop growth stages and was found highest in the residue retention treatment (Table 4). In *rabi* season 2014-15, MBC ranged in between 257-496 mg kg^{-1} and was highest in the green manuring treatment. In both the seasons, MBC was found highest at the PI stage irrespective of RCTs (Table 4). The RMC content varied in the range of 68-137 mg kg^{-1} among the different RCTs throughout the crop growth stages and was found highest in the residue retention treatment in *kharif* season (Table 5). The RMC content was found maximum at the panicle initiation stage of crop development irrespective of the treatments in the *kharif* season 2014, while, in *rabi* season, the RMC was found highest under biochar treatments. However, the oxidizable OC contents did not vary significantly among the RCTs (Table 6).

Table: 3

Energy input (GJ ha^{-1}), energy output (GJ ha^{-1}), energy ratio and net C gain (t ha^{-1}) under resource conservation treatments during *kharif* and *rabi* seasons of 2014-2015

Treatments	*Kharif* season				*Rabi* season			
	Energy input (GJ ha^{-1})	Energy output (GJ ha^{-1})	Energy ratio	Net C gain (t ha^{-1})	Energy input (GJ ha^{-1})	Energy output (GJ ha^{-1})	Energy ratio	Net C gain (t ha^{-1})
CC	23.7b	161ab	6.8a	2.7ab	25.2b	201ab	7.9b	3.5ab
ZT	17.4a	151a	8.7b	2.6a	16.6a	200ab	12.3c	3.7ab
DDS	25.3b	174b	6.9a	2.9ab	30.7d	183a	5.94a	3.0a
BC	26.3b	169b	6.4a	2.8ab	24.9b	226b	9.07b	4.0b
RT	24.3b	171b	6.5a	2.9ab	27.2c	232b	8.5b	4.1b

CC: conventional control; ZT: Zero tillage; DDS: dry direct seeded (with paired row dhaincha); BC: biochar and RT: residue retention and incorporation; In each column, means followed by common letter are not significantly different (p < 0.05) by Tukey–Kramers' HSD test in a given year and plant growth stages.

Table: 4

Microbial biomass carbon content (mg kg^{-1} of soil) at different growth stages of rice crop (cv. *Naveen*) under various resource conservation treatments

Treatments	Plant growth stages							
	Kharif season				*Rabi* season			
	AT	MT	PI	GF	AT	MT	PI	GF
CC	287a	322ab	323a	235a	245a	295a	330a	217a
ZT	319b	326b	397b	331c	305b	375d	469d	367d
DDS	403c	470d	467c	359d	348c	341c	496e	297c
BC	425d	312a	477d	277b	330bc	306b	409b	361d
RT	386c	456c	477d	318c	314b	309bc	433c	239b

CC: conventional control; ZT: Zero tillage; DDS: dry direct seeded (with paired row dhaincha); BC: biochar and RT: residue retention and incorporation; AT, MT and GF represent active tillering, maximum tillering, panicle initiation and grain filling stages, respectively; In each column, means followed by common letter are not significantly different (p < 0.05) by Tukey–Kramers' HSD test in a given year and plant growth stages.

Table: 5

Readily mineralizable carbon content (mg kg^{-1} of soil) at different growth stages of rice crop (cv. *Naveen*) under various resource conservation treatments

Treatments	Plant growth stages							
	Kharif season				*Rabi* season			
	AT	MT	PI	GF	AT	MT	PI	GF
CC	69a	92ab	110a	106a	93c	95b	98a	87a
ZT	94c	107b	122b	109a	60a	67a	91a	126c
DDS	96c	125c	144c	102a	80b	92b	108b	100ab
BC	82b	87a	127b	124b	91c	108c	132c	115b
RT	79.b	92ab	109a	108a	104d	109c	130c	112b

CC: conventional control; ZT: Zero tillage; DDS: dry direct seeded (with paired row dhaincha); BC: biochar and RT: residue retention and incorporation; AT, MT and GF represent active tillering, maximum tillering, panicle initiation and grain filling stages, respectively; In each column, means followed by common letter are not significantly different (p < 0.05) by Tukey–Kramers' HSD test in a given year and plant growth stages.

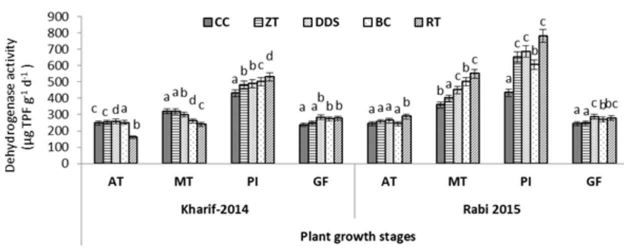
Table: 6
Organic carbon content (g kg^{-1}) at different growth stages of rice crop (cv. *Naveen*) under various resource conservation treatments

Treatments	Plant growth stages							
	Kharif season				*Rabi* season			
	AT	MT	PI	GF	AT	MT	PI	GF
CC	5.4b	5.4a	5.4ab	5.3a	5.7ab	5.6ab	5.5b	5.4ab
ZT	5.2a	5.9b	5.4ab	5.9b	5.5ab	5.4a	5.3a	5.2a
DDS	5.7c	5.4a	5.3a	5.4ab	5.4a	6.4c	5.9c	6.0c
BC	6.0d	6.0ab	5.3a	6.0bc	6.6c	6.3c	5.2a	5.6b
RT	5.0a	6.3c	5.5b	6.3c	7.0d	6.0b	5.4ab	5.4ab

CC: conventional control; ZT: Zero tillage; DDS: dry direct seeded (with paired row dhaincha); BC: biochar and RT: residue retention and incorporation; AT, MT and GF represent active tillering, maximum tillering, panicle initiation and grain filling stages, respectively; In each column, means followed by common letter are not significantly different (p < 0.05) by Tukey–Kramers' HSD test in a given year and plant growth stages.

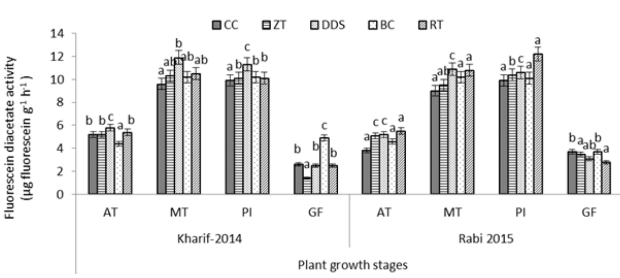
Soil Enzymatic Activity

Six different types of soil enzymes were studied *viz*., dehydrogenase, FDA, β-glucosidase, urease, acid and alkaline phosphatase. The dehydrogenase and fluoresce in hydrolysis activity varied in the range of 160-530 μg TPFg^{-1}d^{-1} (Fig. 1) and 1.4-11.3 μg fluorescein g^{-1} h^{-1} (Fig. 2), respectively. The activity was found highest in residue retention treatment and was the maximum at panicle initiation stage (Fig's 1 and 2) in *kharif* season 2014. The dehydrogenase and fluoresce in hydrolysis activity varied in the range of 242-781 μg TPFg^{-1} d^{-1} (Fig. 1) and 2.8-12.2 μg fluorescein g^{-1}h^{-1} (Fig. 2), respectively in the *rabi* 2014-15. The highest activity was found at panicle initiation stage of rice crop growth. The β-glucosidase and urease hydrolysis activities were varied in the range of 17-50 μg pNG g^{-1} h^{-1} (Fig. 3) and 106-357 μg urea g $^{-1}$ h^{-1} (Fig. 4), respectively. The activities of both β-glucosidase and urease were also found highest in residue retention treatment and was the maximum at panicle



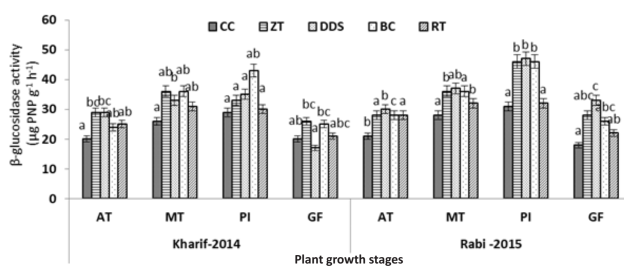
CC: conventional control; ZT: Zero tillage; DDS: dry direct seeded (with paired row dhaincha); BC: biochar and RT: residue retention and incorporation; AT, MT and GF represent active tillering, maximum tillering, panicle initiation and grain filling stages, respectively; In each column, means followed by common letter are not significantly different (p < 0.05) by Tukey–Kramers' HSD test in a given year and plant growth stages.

Fig. 1. Dehydrogenase activity at different crop growth stages under various resource conservation treatments



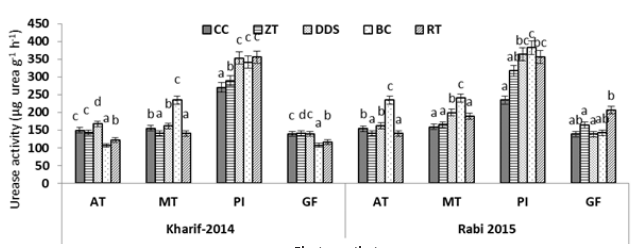
CC: conventional control; ZT: Zero tillage; DDS: dry direct seeded (with paired row dhaincha); BC: biochar and RT: residue retention and incorporation; AT, MT and GF represent active tillering, maximum tillering, panicle initiation and grain filling stages, respectively; In each column, means followed by common letter are not significantly different (p < 0.05) by Tukey–Kramers' HSD test in a given year and plant growth stages.

Fig. 2. Fluorescein di-acetate (FDA) at different crop growth stages under various resources conservation treatments



CC: conventional control; ZT: Zero tillage; DDS: dry direct seeded (with paired row dhaincha); BC: biochar and RT: residue retention and incorporation; AT, MT and GF represent active tillering, maximum tillering, panicle initiation and grain filling stages, respectively; In each column, means followed by common letter are not significantly different (p < 0.05) by Tukey–Kramers' HSD test in a given year and plant growth stages.

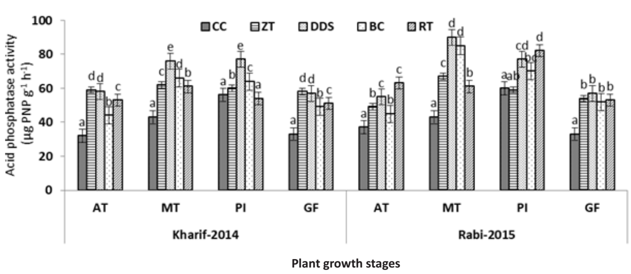
Fig. 3. β-glucosidase activity at different crop growth stages under various resources conservation treatments



CC: conventional control; ZT: Zero tillage; DDS: dry direct seeded (with paired row dhaincha); BC: biochar and RT: residue retention and incorporation; AT, MT and GF represent active tillering, maximum tillering, panicle initiation and grain filling stages, respectively; In each column, means followed by common letter are not significantly different (p < 0.05) by Tukey–Kramers' HSD test in a given year and plant growth stages.

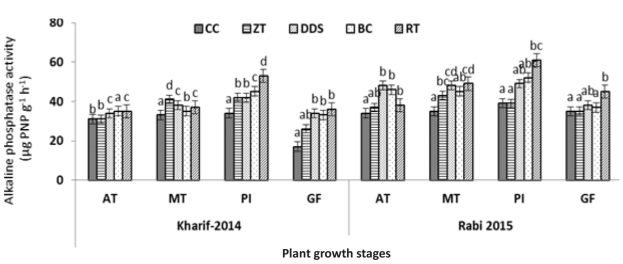
Fig. 4. Urease activity at different crop growth stages under various resources conservation treatments

initiation stage of crop growth (Fig's. 3 and 4) in *kharif* season 2014. In the *rabi* season of 2015, the β-glucosidase and urease hydrolysis activity varied in the range of 18.2-47.2 µg pNG g^{-1} h^{-1} (Fig. 3) and 137-382 µg urea g^{-1} h^{-1} (Fig. 4), respectively. Similar to *kharif* season, the activities of both β-glucosidase and urease was also found highest in residue retention treatment and was the maximum at panicle initiation stage of crop growth (Fig's. 4 and 5). The activities of acid and alkaline phosphatase were in the range of 32-77 µg pNP g^{-1} h^{-1} (Fig. 5) and 17-66 µg pNP g^{-1} h^{-1} (Fig. 6). The activity of acid phosphatase was found higher compared to that of alkaline phosphatase. The activity of acid phosphatase was found highest in paired row rice with *dhaincha* treatment (Fig. 5). On the other hand, the alkaline phosphatase activity was found highest in the residue retention treatment (Fig. 6) in the *kharif* season of 2014. In the *rabi* season, the acid phosphates varied 37-82 µg pNP g^{-1} h^{-1} among the treatments (Fig. 5), and was found highest under residue incorporation treatments. Alkaline phosphatase was also found highest at panicle initiation stage of crop growth during *rabi* season (Fig. 6).



CC: conventional control; ZT: Zero tillage; DDS: dry direct seeded (with paired row dhaincha); BC: biochar and RT: residue retention and incorporation; AT, MT and GF represent active tillering, maximum tillering, panicle initiation and grain filling stages, respectively; In each column, means followed by common letter are not significantly different ($p < 0.05$) by Tukey–Kramers' HSD test in a given year and plant growth stages.

Fig. 5. Acid phosphatase activity at different crop growth stages under various resources conservation treatments



CC: conventional control; ZT: Zero tillage; DDS: dry direct seeded (with paired row dhaincha); BC: biochar and RT: residue retention and incorporation; AT, MT and GF represent active tillering, maximum tillering, panicle initiation and grain filling stages, respectively; In each column, means followed by common letter are not significantly different ($p < 0.05$) by Tukey–Kramers' HSD test in a given year and plant growth stages.

Fig. 6. Soil alkaline phosphatase activity at different crop growth stages under various resources conservation treatments

Yield

In the present study, grain yield and straw yield were found highest in the residue incorporation treatments, which was due to higher nutrients availability (Jat *et al.,* 2014). The yield was relatively less in ZT treatment, which can be attributed because of initial year of treatment imposition (Giller *et al.,* 2009; Ghimire *et al.,* 2017), which leads to relatively poor seed-soil contract and compaction. There is a setback to yield in initial year of ZT but it is generally overcome within 2-3 years depending on soil carbon build up and soil aggregation status. The recovery also takes place due to less soil disturbance and addition of crop residues (Ladha *et al.,* 2009). The supply of organic matter to the soil through residue incorporation, mulching and green manure is important for maintaining and enhancing soil fertility (Bhattacharyya *et al.,* 2012a; Dash *et al.,* 2017). Organic substrates come from crop residues or green manure crops; it provides feed for the soil life and mineral nutrients for the plants.

Energy Saving and Net Carbon Gain

We got less energy use in ZT technology. By adapting reduced-tillage in rice – green gram cropping system, 14% reduction of energy use has been reported by Khambalkar *et al.* (2010). Many authors also demonstrate that ZT-wheat seeding technology could play an important role in saving inputs, turnaround time, reducing energy usage, and environmental pollution, and improving farmer's income (Parihar *et al.,* 2017; Yadav *et al.,* 2018). Therefore, there is a possibility of introduction and adaptation of ZT in rice based cropping system in eastern India in the light of energy savings.

Soil Carbon Pools

Soil MBC regulates SOM decomposition and nutrient cycling, and thus plays a key role in maintaining function and sustainability of terrestrial ecosystems. The MBC has been included in current soil monitoring concepts due to its rapid response and high sensitivity to management practices and environmental changes. In the present experiment, addition of plant biomass added treatments like residue, *dhanicha* and biochar resulted into higher MBC content over control. Plant biomass provides a potent source of labile C to soil. Hence, its incorporation in soil leads to higher labile C pool (Bhatia *et al.,* 2005). Soil labile C acts as a readily decomposable substrate for soil micro organisms and as a short-term reservoir of plant nutrients (Garcla-orenes *et al.,* 2010; Bhattacharyya *et al.,* 2012a, 2013; Dash *et al.,* 2017).The soluble carbon fraction is also an important factor in respect to SOM turnover in agricultural soils.

Soil Enzymatic Activities

SOM is the substrate for soil enzymes and protects them through the formation of enzyme complexes with clay and humus (Tabatabai, 1994). Dehydrogenase activity basically depends on the metabolic state of the soil biota. We observed a significant increase in soil enzymatic activity in residue retention treatment as compared to other treatments, which may be due to the addition of plant residues which led to availability of labile soil carbon pools (Bhattacharyya *et al.,* 2012b). Total microbial activity, in terms of FDA hydrolysis, has been used to determine amounts of active micro flora producing extracellular enzymes (Adam and Duncan, 2001). These enzymes can persist in soil as parts of inorganic complexes or in association with organic colloids. The β-Glucosidase is widely abundant, and is synthesized by soil micro-organisms in response to the presence of suitable substrates. The highest β-glucosidase activity was recorded in the plots with residue retention due to the enrichment in fresh plant materials of a cellulolytic nature, which acted as substrates for the β-glucosidase enzyme. Urease activity decreased with the increasing application of NH_3 based-nitrogen fertilizers probably due to presence of the end product of the enzymatic reaction (NH_4^+) (Ghimire *et al.,* 2017). The acid and alkaline phosphatase activity was found highest in the green manure treatment and residue retention treatment, respectively due to availability of higher substrates.

4. CONCLUSIONS

More energy saving in ZT; higher C gain, soil C pool and enzymatic activities in ZT and residue retention are the indication of sustainability, improved soil health, C-sequestration potential. However relatively less yield in ZT could be recovered with few (3-4) years when there would be build up of sufficient amount of organic C. Therefore, we should judge the system-economics as a whole, including cost of energy use and C gain not only on yield basis. Hence, ZT and or ZT with residue retention may be recommended in rice-rice cropping system in lowland ecology having heavy textured soil in eastern India for environmental sustainability.

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