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Climate Smart Agriculture Influences Soil Enzymes Activity under Cereal-based Systems of North-West India

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Soil enzyme activities are important indicators of changes in management practices in crop production systems. Measurements of different soil quality parameters are essential for assessing the impact of soil and crop management practices. Keeping this in view, an experiment was conducted to evaluate the enzyme activities namely, dehydrogenase (DHA), β-glucosidase, acid and alkaline phosphatase, fluorescein diacetate hydrolases (FDH), cellulase, urease and arylsulphatase in soil after 7 years of the experimentation with same management practices. The treatments were conventional rice-wheat system (Sc1), partial conservation agriculture (CA)-based rice-wheat-mungbean system (Sc2), partial climate smart agriculture (CSA)-based rice-wheat-mungbean system (Sc3), partial CSA-based maize-wheat-mungbean system (Sc4), full CSA-based rice-wheat-mungbean system (Sc5), and full CSA-based maize-wheat-mungbean system (Sc6). Soil samples were collected before sowing, maximum tillering, flowering, and at harvest of wheat crop from surface layer (0-15 cm soil depth). Partial CA-based system (Sc2) exhibited higher DHA activity over others. Also DHA activity in soil was higher at maximum tillering (16%), flowering (11%) and after harvesting (3%) in rice-based CSA systems (mean of Sc3 and Sc5) over maize-based systems (mean of Sc4 and Sc6). On average, β-glucosidase and alkaline phosphatase activity was significantly higher in soils of maize based systems than rice based systems. On average, improved practices (CA and CSA) based scenarios (Sc2-Sc6) recorded 15 per cent higher FDH activity over farmers' practice/ CT (Sc1). Significant interaction effect was observed between the managements and enzyme activities. The CSA managements were found beneficial in improving soil enzyme activities and thereby helping in improving nutrient cycling besides influencing other soil properties in long run.

Key words: Climate smart agriculture, soil enzymes, cereal systems, soil biological quality

Soil enzymes are important catalysts for decomposition of soil organic matter (SOM) and nutrient cycling and strongly influence energy transformation, nutrient mobilization, environmental quality, and agronomic productivity. Soil enzymes quickly respond to modifications in soil and crop management practices and therefore provide early detection of changes much faster than other soil quality parameters. The availability of nutrients and crop productivity were determined by qualitative and quantitative changes in soil enzymes (Dick and Kandeler 2005). Soil enzyme activities were influenced by different agricultural practices like cropping systems, tillage, crop establishment, crop residues, irrigation water, nutrient, and crop management, thereby influencing the sustainability of crop production (Srinivasarao *et al*. 2014). Adverse impacts of tillage, cropping systems, and residues removal on soil enzyme activities and availability of plant nutrients have been observed by Celika *et al*. (2011). Soil physical and chemical properties, urease activity and acid phosphatase activity are known to improve by application of organic amendments such as farmyard manure (FYM), crop residues, and composts, which increases SOM, and enhances soil quality.

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Climate smart agriculture (CSA) practices based on conservation agriculture (CA) principles of zero tillage (ZT), residue management and efficient crop rotations along with precise irrigation water and nitrogen (N)-management using sub-surface drip irrigation (SDI) improved system and water productivity, and farm profitability in cereal (rice/ maize based) systems of north-west India (Jat *et al*. 2019c). Improvement in soil physical properties (Jat *et al*. 2018), nutrient availability (Jat *et al*. 2018), biological soil quality (Choudhary *et al*. 2018a) and crop productivity (Sharma *et al*. 2019) with soil organic carbon (SOC) enrichment (Datta *et al*. 2019; Jat *et al*. 2019a, b) are the other advantages of CSA practices. In addition to that there are savings of input resources like energy, labour, water and other valuable natural resources.

In cereal based systems, soil enzymes activities were evaluated by many researchers under different agriculture management practices (Choudhary *et al*. 2018a, b; Bergstrom *et al*. 2000). In north-west India, Choudhary *et al*. (2018a) evaluated dehydrogenase activity (DHA) and alkaline phosphatase activity (APA) in soils under CA-based maize-wheat-mungbean and rice-wheat-mungbean system and reported 210 and 49 per cent higher DHA and APA in soils under former and 140 and 42 per cent under later system over conventional farmers' practice (rice-wheat system). Bergstrom *et al*. (2000) observed significant influence on activities of many enzymes under no-tillage along a topographic and soil textural gradient. In subtropical environment higher DHA, urease, protease, phosphatase and β-glucosidase activities were observed under no tilled soil over conventional tillage (CT) system in sorghum cultivation (Roldan *et al*. 2005).

Intensive tillage before sowing of next crop in conventional/ traditional agricultural practices mixes the stubbles/roots with soil. But in CSA, crop stubbles and roots are kept as such in field after crop harvesting and remaining loose residues cover the soil surface instead of burning or removal. Therefore, higher enzymes activity in soil would be recorded due to ZT and crop residue retention under CSA than conventional agriculture practices. We hypothesized that soil enzyme activities with CSA based management practices will be improved at different growth stages compared to those of CT-based management practices. Thus, the objectives of this study were to evaluate the activity of soil enzymes and the effect of scenarios, crop growth stage and their interactions on soil enzymes after 7 years of CSA practices in NW India. Contrast effect between rice- and maize-based systems on soil enzymes was also studied.

Materials and Methods

Field experimental design

Soil samples were taken from the experimental farm of the Indian Council of Agricultural Research (ICAR) - Central Soil Salinity Research Institute (CSSRI) (29°70′ N, 76°95′ E), Karnal, India. Soil type is loam in texture with 34% sand, 46.1% silt and 19.9% clay. It falls under Typic Natrustalf category (Soil Survey Division Staff 1993). Climate is extreme hot and dry (April-June) to wet summers (July-September) and cold dry winters (October-March). Average annual maximum and minimum temperature is 30 and 17 °C, respectively with annual precipitation of 650 mm.

The experiment was started in 2009, with four cereal-based scenarios (Sc1, Sc2, Sc3 and Sc4) having different cropping system, tillage and residue management practices. In May 2016, two more management scenarios of sub-surface drip irrigation (SDI) (Sc5 and Sc6) were introduced in the subdivided plots of Sc3 and Sc4. Thus, the six scenarios (Sc) are described in table 1. The Sc3 and Sc4 treatments were based on principles of CA practices and called partial climate smart agriculture (CSA). However, the Sc5 and Sc6 treatments comprised of Sc3 and Sc4 treatments plus precise management of irrigation water and N using sub-surface drip irrigation (SDI) and were called full CSA. Standard crop management practices were followed in all the treatments for all crops and cropping systems except Sc1, where farmer's practices were followed based on the survey done in nearby areas (Table 1).

Soil sampling, processing and analysis

In order to explore the effect of management practices (CT v/s CSA) on different enzyme activities like DHA, acid phosphatase, alkaline phosphatase, β-glucosidase, fluorescein diacetate hydrolases (FDH), arylsulphatase (ARS), urease and cellulase, soil samples were collected at different crop cultivation stages of wheat (before sowing, maximum tillering, flowering and harvesting) in the year 2016-17. From each plot, samples were taken at 0-15 cm depth from nine locations and composite samples were prepared separately. Fresh soil samples were immediately kept in a refrigerator at 4 °C till analysis of different enzymes. The DHA, acid phosphatase, alkaline

Table 1. Scenarios of agricultural change, crop rotation, tillage, crop establishment, and residue management

Scenario	Scenario description	Crop rotations	Tillage	Crop establishment	Residue management
Sc1	Farmer's practice	Rice-wheat- fallow	CT-CT	Rice: Transplanting Wheat: Broadcast	All residue removed
Sc2	Partial conservation agriculture (CA) based system	Rice-wheat-mungbean	CT-ZT-ZT	Rice: Transplanting Wheat: Drill seeding Mungbean: Drill/relay	Full (100%) rice and anchored wheat residue retained on soil surface; full mungbean residue incorporated
Sc3	Partial climate smart agriculture (CSA) based rice system	Rice-wheat-mungbean	ZT-ZT-ZT	Rice: Drill seeding Wheat: Drill seeding Mungbean: Drill/relay	Full (100%) rice and mungbean; anchored wheat residue retained on soil surface
Sc4	Partial CSA based maize system	Maize-wheat-mungbean	ZT-ZT-ZT	Maize: Drill seeding Wheat: Drill seeding Mungbean: Drill/relay	Maize (65%) and full mungbean; anchored wheat residue retained on soil surface
Sc5	Full CSA based rice system (Sc3+SDI)	Rice-wheat-mungbean	ZT-ZT-ZT	Same as in scenario 3	Same as in scenario 3
Sc6	Full CSA based maize system (Sc5+SDI)	Maize-wheat- mungbean	ZT-ZT-ZT	Same as in scenario 4	Same as in scenario 4

where, CT = conventional tillage; ZT = zero tillage; SDI = sub-surface drip irrigation

phosphatase, β-glucosidase, ARS and urease activities were estimated as described by Tabatabai (1994). Cellulase activity was determined by the method of Hope and Burns (1987), while, FDH assay was done by the method of Green *et al*. (2006).

Statistical analysis

The data were subjected to analysis of variance (ANOVA) and using the general linear model procedure of the SPSS Window version 17.0 (SPSS Inc., Chicago, USA). Treatment means were separated by least square design (LSD) test at 5% level of significance ($p<0.05$). To determine the effect of scenarios, crop growth stages (fixed factors) and their interaction effect on the different enzyme activities (dependent variable), two-way ANOVA was carried out. Linear contrasts were used to compare single or multiple treatments against one another.

Results and Discussion

Dehydrogenase and β-glucosidase activity

Significant variation in DHA was observed in soils under different scenarios (Table 2). Irrespective of crop growth stages, on average partial CA-based system (Sc2) recorded highest DHA activity (124 µg TPF g^{-1} soil h^{-1}) over other scenarios. The Sc2 also showed 42 and 46 per cent higher DHA activity over CSA-based rice (mean of Sc3 and Sc5) and maize (mean of Sc4 and Sc6) based systems, respectively irrespective of crop growth stages. Whereas, farmers practice (Sc1) had resulted 27 and 32 per cent higher DHA over CSA-based rice and maize-based systems, respectively (Table 2). The DHA was significantly higher at maximum tillering (16%) and flowering stage (11%) in rice over maize-based CSA system whereas before sowing higher DHA (11%) was reported in maize-based CSA system. Partial rice-based CA system (Sc2) showed higher DHA before sowing (30.4%), maximum tillering (16.4%) and after harvesting (72.6%) of wheat over farmers' practice (Sc1). On average, in Sc2, DHA activity was significantly higher before sowing (59 and 54%), at maximum tillering (46 and 54%), at flowering (10 and 21%) and after harvesting of wheat (47 and 48%) as compared to rice and wheat-based CSA system, respectively.

Dehydrogenase activity in soil was influenced by different crop and soil management practices followed. Higher DHA in partial CA-based system (Sc2) might be due to mixing of wheat and mungbean residues which were retained at soil surface under ZT with soil during pudlling before rice transplanting. This mechanism facilitated the conversion of crop residue carbon to SOC as Guptachoudhury (2010) reported a conversion rate of 6.4% in puddle rice-based systems. This might have facilitated higher DHA in partial CA-based system. There is hardly any

Table 2. Dehydrogenase and β-glucosidase activity in soils under different crop management scenarios

Scenarios/ crop growth stages	Dehydrogenase (μg TPF g^{-1} soil h^{-1})					β-glucosidase (μg PNP g^{-1} soil h^{-1})				
	Before sowing	Maximum tillering	Panicle initiation	Harvesting	Mean	Before sowing	Maximum tillering	Panicle initiation	Harvesting	Mean
Sc1	69^{B}b	134^{B}a	99^{A}ab	95^{BC}b	99^{B}	109^{B}b	117^{E}b	137^{B}a	71^{D}c	109^{B}
Sc2	90^{A}b	156^{A}a	87^{A}b	164^{A}a	124^{A}	134^{A}b	171^{A}a	134^{B}b	110^{AB}c	137^{A}
Sc3	37^{C}c	97^{C}a	63^{B}b	106^{B}a	76^{C}	140^{A}a	129^{D}b	140^{B} a	93^{C} c	126^{AB}
Sc4	38^{C} b	83^{C}a	45^{B}b	94^{BC}a	65^{C}	127^{ABa}	139^{C}a	137^{B} a	105^{B}a	127^{AB}
Sc5	36^{C}c	72^{C}b	92^{A}a	68^{D}b	67^{C}	109^{B}b	151^{B}a	136^{B}a	76^{D}c	118^{AB}
Sc6	44^{C}d	59^{C}c	93^{A}a	75^{CD}b	68^{C}	140^{A}b	125^{DE}bc	174^{A} a	120^{A}c	140^{A}

where, Sc1=conventional rice-wheat system, Sc= partial CA-based rice-wheat-mungbean system, Sc3= partial CSA-based rice-wheat-mungbean system, Sc4= partial CSA-based maize-wheat-mungbean system, Sc5=full CSA-based rice-wheat-mungbean system, Sc6= full CSA-based maize-wheat-mungbean system.
Same upper and lower case letters are not significantly different at $p<0.05$ among the scenarios in a column and sampling stages of wheat in rows, respectively according to LSD test for separation of mean.

information on conversion rate of crop residue carbon to SOC under CA-based systems. Similarly, in conventional system (Sc1), there was no burning or removal of the stubbles and roots of the crops during tillage/puddling; supplying carbon to soil upon decomposition and thereby explaining higher DHA in soil. Higher DHA in Sc2 might be due to the availability of labile carbon upon decomposition of previous year's incorporated wheat, mungbean and rice crop residues which facilitates higher microbial activity (Singh *et al*. 2015; Zhao *et al*. 2019). Although higher DHA activity was observed under ZT conditions by other researchers (Bergstrom *et al*. 2000; Choudhary *et al*. 2018a, b). Dehydrogenase is only present in viable cells and involved in the oxidation of SOM and not in stabilized soil complexes. Our results are in disagreement with the observations where soil amended with crop residues under ZT shows higher dehydrogenase activity (Roldan *et al*. 2005). The observed lower DHA activity in response to CSA-based system compared to Sc2 and Sc1 might be due to the resiliency of the enzyme to crop residue inputs (Singh *et al*. 2015). Availability of labile carbon produced after decomposition of previous year's wheat and mungbean residues by microorganisms might have resulted higher DHA activity in soils at flowering and after harvest of the rice crop.

Being the responsible enzyme for carbon cycle in soil, on average β-glucosidase activity was significantly higher in soils before sowing (7.2%), panicle initiation (12.7%) and after harvesting (33.1) of maize-based (mean of Sc4 and Sc6) over rice-based CSA systems (mean of Sc3 and Sc5). In maximum tillering stage, higher β-glucosidase activity was observed under rice systems (140 μg PNP g^{-1} soil h^{-1}) over maize (132 μg PNP g^{-1} soil h^{-1}) (Table 2). Partial CA-based system (Sc2) recorded significantly higher β-glucosidase activity before sowing (23%), maximum tillering (46%) and after harvesting (55%) over conventional system (Sc1). On average, CSA practices (average of Sc3, Sc4, Sc5 and Sc6) recorded significantly higher β-glucosidase activity in soils before sowing (19.3%), maximum tillering (22.2%), panicle initiation (5.3%) and after harvest (42%) compared to farmers practice (Sc1) (Table 2).

Higher β-glucosidase activity in soils under maize-based systems might be due to the higher residue load from maize residues leading to more carbon input to soil. This is also supported by the higher soil carbon concentration under maize-based systems over rice-based CSA systems (data not shown). Moreover, during flowering stage the decomposition of the previous year's residue were at peak which might facilitate higher β-glucosidase activity at maize-based systems. At maximum tillering stage, higher β-glucosidase activity in soils under rice based CSA systems might be due to labile carbon input from fibrous root mass of rice in previous years. Pausch and Kuzyakov (2018) reported the highly dynamic nature of rhizodepositions which are incorporated into the microorganisms, soil organic matter, and decomposed to CO_2 explaining the higher β-glucosidase activity in soil under rice. Bergstrom *et al*. (1998, 2000) also reported higher β-glucosidase activity in no-till soil over conventional agriculture in varying textured soil of Canada. Incorporation of crop residues in partial CA-based system (Sc2) favors microbial activity which resulted higher β-glucosidase activity in soil over conventional system (Sc1) (Singh *et al.* 2015; Zhao *et al*. 2019).

Table 3. Acid and alkaline phosphatase activity in soils under different management scenarios in cereal-based systems

Scenarios/ crop growth stages	Acid phosphatase (µg PNP g^{-1} soil h^{-1})					Alkaline phosphatase (µg PNP g^{-1} soil h^{-1})				
	Before sowing	Maximum tillering	Panicle initiation	Harvesting	Mean	Before	Maximum sowing	Panicle tillering	Harvesting initiation	Mean
Sc1	95^{A}a	105^{A}a	88^{B}a	31^{A}b	80A	121^{A}a	59^{D}c	62^{C}c	93^{B}b	84B
Sc2	92^{A}a	118^{A}a	60^{C}b	37^{A}b	77A	108^{B}a	76^{C}a	80^{BC}a	95^{B}a	90AB
Sc3	77^{A}b	119^{A}a	64^{BC}b	30^{A}b	73A	85^{C}b	133^{A}ab	168^{A}a	85^{B}b	118A
Sc4	84^{A}c	121^{A}a	97^{A}b	29^{A}d	83A	85^{C}c	120^{A}b	153^{A}a	89^{B} c	112A
Sc5	114^{A}a	120^{A}a	108^{A}a	32^{A}b	94A	117^{AB} a	98^{B}b	91^{B}c	62^{C}d	92AB
Sc6	102^{A}ab	110^{A}a	97^{A}b	23^{A}c	83A	91^{C}b	86^{BC}b	146^{A}c	117^{A}a	110A

where, Sc1=conventional rice-wheat system, Sc2= partial CA-based rice-wheat-mungbean system, Sc3= partial CSA-based rice-wheat-mungbean system, Sc4= partial CSA-based maize-wheat-mungbean system, Sc5=full CSA-based rice-wheat-mungbean system, Sc6= full CSA-based maize-wheat-mungbean system.

Same upper and lower case letters are not significantly different at $p < 0.05$ among the scenarios in a column and growth stages of wheat in rows, respectively according to LSD Test for separation of mean.

Acid and alkaline phosphatase activity

Acid phosphatase activity was statistically similar in each growth stage irrespective of scenarios (Table 3). Among the crop growth stages, higher acid phosphatase activity ($p<0.05$) was observed at maximum tillering stage. Before sowing of wheat, higher (13.7%) acid phosphatase activity was observed in soils of CSA-based systems (average of Sc5 and Sc6) over Sc1. At maximum tillering, about 12% higher acid phosphatase activity was observed in improved management (CA and CSA) based systems (mean of Sc2-Sc6) over Sc1. In maize-based systems, at panicle initiation stage 12.8 per cent higher acid phosphatase activity was recorded over rice-based systems. Significantly higher alkaline phosphatase activity was observed in panicle initiation (15.4%) and after harvesting stage (40%) in soils of maize over rice-based CSA systems (Table 3). At maximum tillering (74%) and panicle initiation stage (106%), significantly higher alkaline phosphatase activity was observed in CSA-based systems over Sc1. In Sc2, alkaline phosphatase activity was about 29% higher at maximum tillering and panicle initiation stage over Sc1 (Table 3).

Before sowing of wheat, higher acid phosphatase activity in soils of CSA-based system (Sc5 and Sc6) might be due to the previous year's residues left in the soil which was decomposing and supplying labile carbon to microbes moreover roots of the crops were also contributed in total phosphatase activity leading to higher acid phosphatase activity. Higher rhizodeposition in root zone led to acidity which further accentuates the acid phosphatase activity (Pausch and Kuzyakov 2018). Higher acid phosphatase activity in soils at maximum tillering stage of wheat is attributed to differential residue decomposition leading to varying rates of labile carbon release in those systems. Higher alkaline phosphatase activity in maize-based system might be due to higher root biomass and above ground maize residues retained in soil. Choudhary *et al*. (2018a, b) also reported higher alkaline phosphatase activity under CA-based management practices. Crop rotation particularly inclusion of legume has played an important role in enzyme activities observed in those CSA-based scenarios. In our case, legume integration in rice-wheat and maize-wheat systems has facilitated higher microbial activity leading to release of both acid and alkaline phosphatase activity in soil. Crop rotation had more effect on soil quality attributes than did tillage practice (Campbell *et al*. 1999).

Fluorescein diacetate hydrolases

The FDH activity (µg fluorescein g^{-1} soil h^{-1}) was found higher in Sc1 and Sc2 before sowing of wheat but after harvesting it was higher in Sc3 and Sc4, whereas at maximum tillering stage it was higher in Sc5 and Sc6 (µg fluorescein g^{-1} soil h^{-1}) (Fig. 1). In all scenarios it was lowest at flowering stage. This result was observed not only due to difference in management systems but there is also role of cropping season as seasonal variation also influences enzyme activities. An increase of 15 per cent in FDH activity was recorded in CSA-based scenarios (Sc2-Sc6) over CT (Sc1). The FDH activity is an important indicator of general microbial activity and in the full CA-based scenarios microbes are getting better conditions than CT which favors enzyme activities (Choudhary *et al*. 2018b).

Arylsulphatase

At different growth stages of wheat crop, ARS

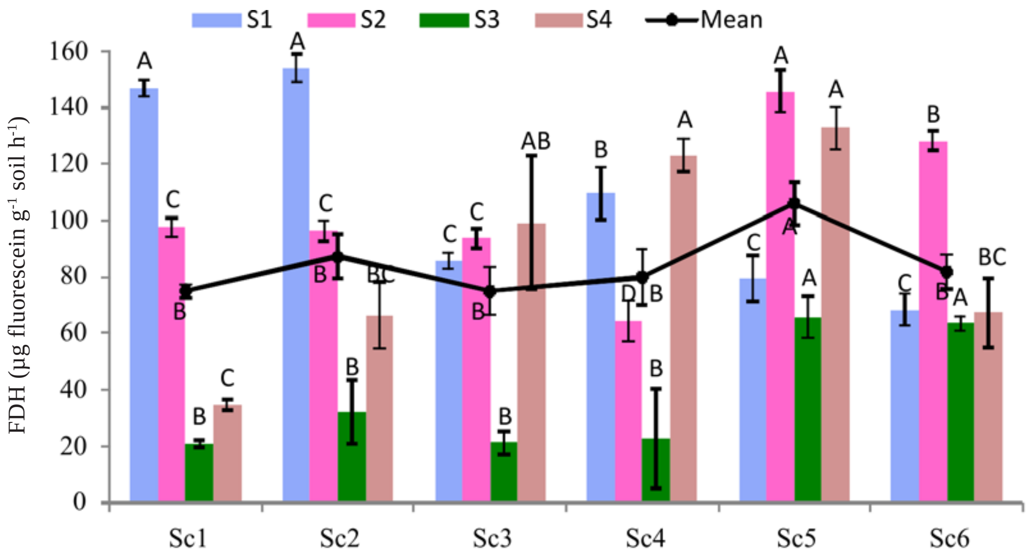

Fig. 1. Fluorescein activity in soils under different management scenarios in cereal based systems
where, Sc1 = conventional rice-wheat system, Sc2 = partial CA-based rice-wheat-mungbean system, Sc3 = partial CSA-based rice-wheat-mungbean system, Sc4 = partial CSA-based maize-wheat-mungbean system, Sc5 = full CSA-based rice-wheat-mungbean system, Sc6 = full CSA-based maize-wheat-mungbean system.
S1: before sowing; S2: maximum tillering; S3: panicle initiation; S4: after harvesting of crop
Same upper case letters are not significantly different at *p<0.05* according to LSD test for separation of mean
Vertical bars indicate ±S.E. of mean of the observed values.

activities were recorded in the range of 22.8-162.8 µg p-NP g^{-1} soil h^{-1} (Fig. 2). It was first increased from sowing to tillering and then decreased from tillering to flowering and harvest stage. A particular trend of ARS activity was recorded irrespective of scenarios, highest at tillering and lowest at harvesting, it may be due to the effect of crop growth stage. Such type of result is also reported by Bera *et al*. (2017) who reported higher enzyme activity at the vigorous vegetative growth stages (such as maximum tillering and jointing stages) than at the reproductive growth stages (such as grain filling and maturity stages). It was 14 per cent higher in CSA systems (Sc2-Sc6) than farmer's practice. In CA-based scenarios presence of residues can be linked with higher activities of ARS. Sulphatases are reported to be also found as exoenzymes in the soil and closely linked to organic matter (Kotkova *et al*. 2008).

Urease activity

There was hardly any effect of growth stages and management practices noticed on urease activity. Except at tillering stage it was slightly higher in CA-based scenarios than to CT scenario (Fig. 3). Sufficient application of urea has been done in all scenarios which results in very less difference in urease activity among scenarios. Slight difference was also observed which may be due to the crop residue management. Crop residue favors growth of soil microflora and enhances production of intra and extra-cellular urease activity in soil (Mobley and Hausinger 1989).

Cellulase activity

Cellulase activity was found to lowest at sowing stage and then increased at different stages (Fig. 4). The CSA-based scenarios showed 26 per cent higher cellulase activity (29.71 µg glucose g^{-1} soil h^{-1}) than CT scenario (23.57 µg glucose g^{-1} soil h^{-1}). Residue retention and zero tillage are the main reasons behind the higher cellulase activity under CA-based scenarios (Balota 2004).

Interactions effect

The analysis of variance showed that most of the enzymes were significantly influenced by scenarios, crop growth stages and their interactions *i.e.* scenario × stage, except few instances (Table 4). The interaction effect of scenarios and crop growth stages were non-significant for acid and alkaline phosphatase activity, respectively. Contrast analysis showed that there was significant influence between rice- and maize-based systems for DHA, ARS and β-glucosidase enzymes (Table 4). Significant

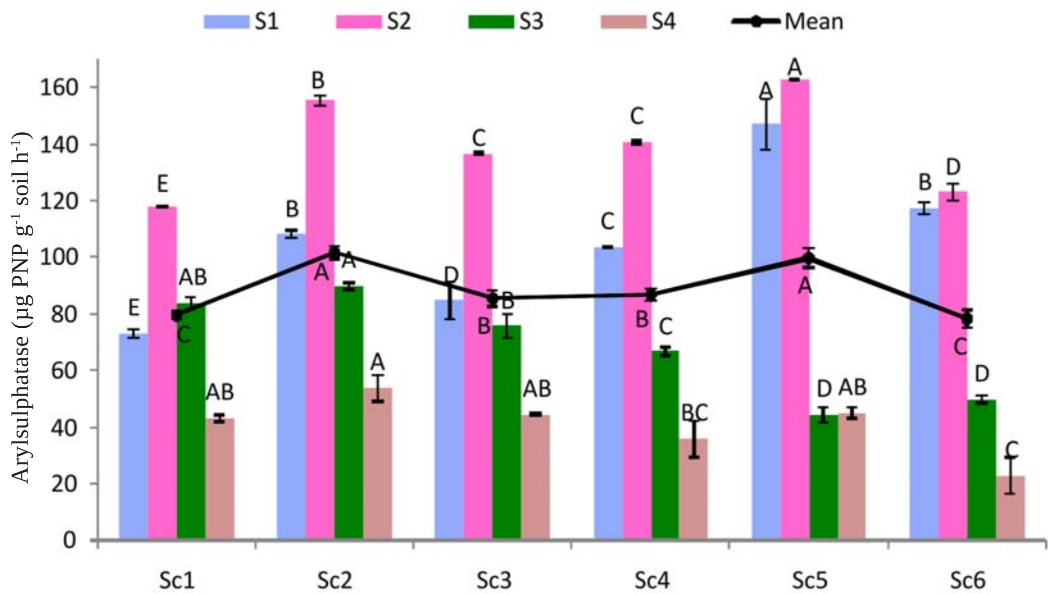

Fig. 2. Arylsulphatase activity in soils under different management scenarios in cereal based systems

where, Sc1 = conventional rice-wheat system, Sc2 = partial CA-based rice-wheat-mungbean system, Sc3 = partial CSA-based rice-wheat-mungbean system, Sc4 = partial CSA-based maize-wheat-mungbean system, Sc5 = full CSA-based rice-wheat-mungbean system, Sc6 = full CSA-based maize-wheat-mungbean system.

S1: before sowing; S2: maximum tillering; S3: panicle initiation; S4: after harvesting of crop

Same upper case letters are not significantly different at *p<0.05* according to LSD test for separation of mean

Vertical bars indicate ±S.E. of mean of the observed values.

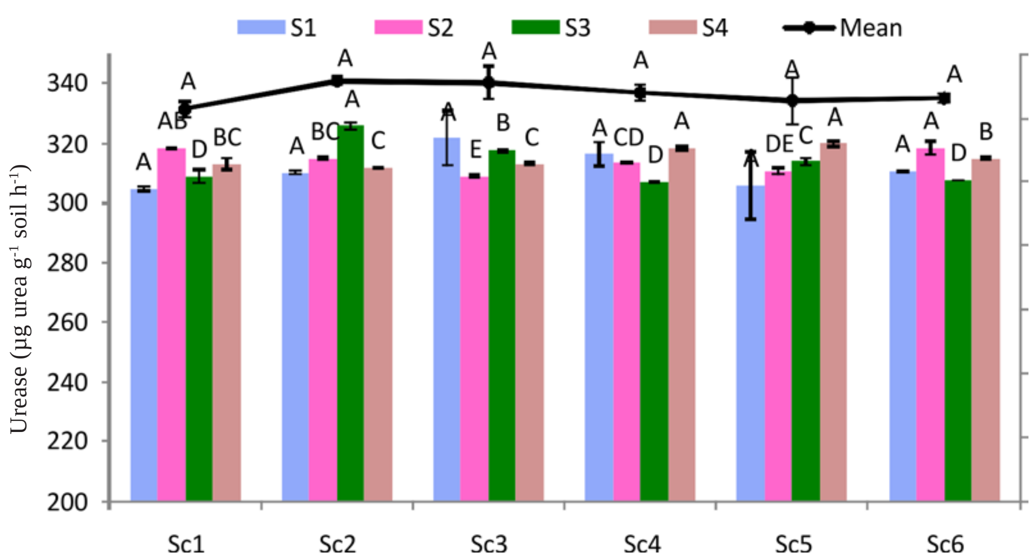

Fig. 3. Urease activity in soils under different management scenarios in cereal based systems

where, Sc1=conventional rice-wheat system, Sc2 = partial CA-based rice-wheat-mungbean system, Sc3 = partial CSA-based rice-wheat-mungbean system, Sc4 = partial CSA-based maize-wheat-mungbean system, Sc5 = full CSA-based rice-wheat-mungbean system, Sc6 = full CSA-based maize-wheat-mungbean system.

S1: before sowing; S2: maximum tillering; S3: panicle initiation; S4: after harvesting of crop

Same upper case letters are not significantly different at *p<0.05* according to LSD test for separation of mean

Vertical bars indicate ±S.E. of mean of the observed values.

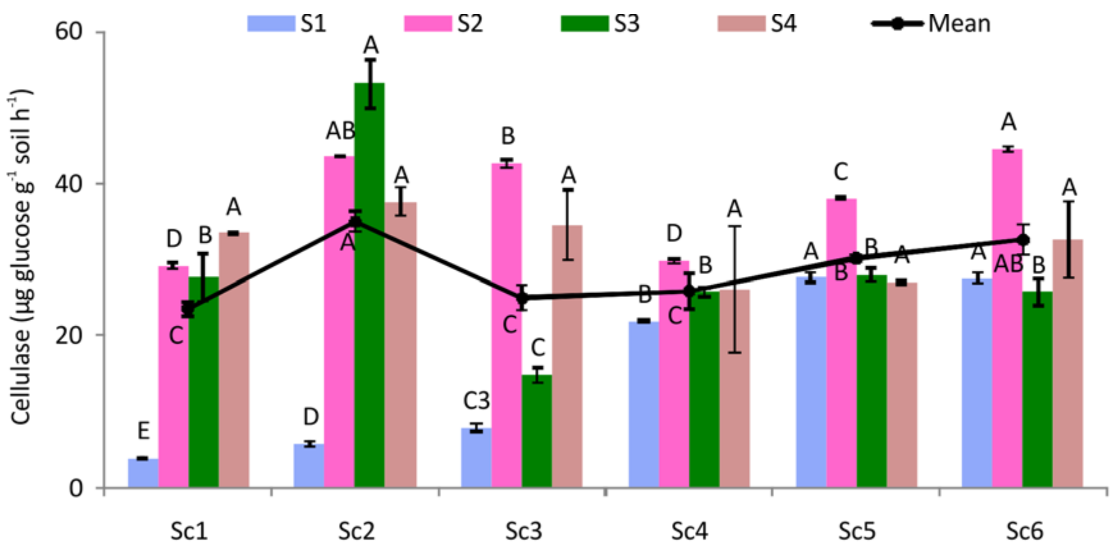

Fig. 4. Cellulase activity in soils under different management scenarios in cereal based systems
where, Sc1 = conventional rice-wheat system, Sc2 = partial CA-based rice-wheat-mungbean system, Sc3 = partial CSA-based rice-wheat-mungbean system, Sc4 = partial CSA-based maize-wheat-mungbean system, Sc5 = full CSA-based rice-wheat-mungbean system, Sc6 = full CSA-based maize-wheat-mungbean system.
S1: before sowing; S2: maximum tillering; S3: panicle initiation; S4: after harvesting of crop
Same upper case letters are not significantly different at $p<0.05$ according to LSD test for separation of mean
Vertical bars indicate ±S.E. of mean of the observed values.

Table 4. Interactions among the scenarios, crop growth stages and contrast effect between rice and maize based systems

Source of variation	Statistical significance (P value)							
	Dehydrogenase	Acid phosphatase	Alkaline phosphatase	Arylsulfatase	Urease	β-glucosidase	FDH	Cellulase
Scenario	<0.0001*	NS	0.0010*	<0.0001*	NS	<0.0001*	0.0077*	0.0005*
Crop growth stage	<0.0001*	<0.0001*	NS	<0.0001*	NS	<0.0001*	<0.0001*	<0.0001*
Scenario × crop growth stage	<0.0001*	0.0240*	<0.0001*	<0.0001*	0.0009*	<0.0001*	<0.0001*	<0.0001*
Contrast – Rice-wheat: Maize-wheat systems	<0.0001*	NS	NS	<0.0001*	NS	0.0002*	NS	NS

interactions among the scenarios, crop growth stages and their interactions on the soil enzymes might be due to the effect of climate smart agriculture practices followed. Microbial population enhanced due to residue retention (Helgason *et al*. 2009) which provides stimulating substrate for their growth and proliferation (Ghimire *et al*. 2014) leading to higher enzyme activities. Residue retention with ZT had resulted higher population counts of total bacteria, fluorescent pseudomonas, and actinomycetes over residue removal (Govaerts *et al*. 2008).

Conclusions

Climate smart agriculture (CSA) practices in cereal (rice and maize) based systems of western Indo-Gangetic plains strongly influenced the soil enzyme activities. In general, higher activities of dehydrogenase (DHA), acid phosphatase, fluorescein diacetate hydrolases (FDH), cellulase, urease and arylsulphatase were associated with the rice-based system. However, β-glucosidase and alkaline phosphatase activity was recorded higher with maize based systems. Dehydrogenase activity was much induced by residue incorporation compared to residue retention in rice-based system and found higher with partial CA-based system. In CSA-based systems, sustainable intensification of rice-wheat system through ZT coupled with residue retention and mungbean integration for a considerable period helped in enhancing soil quality which resulted in improved soil enzyme activities. In the current era of climate change, crop and soil management practices has important implications in accessibility of nutrients to plants because crop residues release nutrients upon decomposition which in long run could help in savings of precious nutrients besides improving overall soil quality and carbon enrichment. Future studies should be conducted on individual contribution of belowground (roots, rhizodeposition) and above ground biomass (crop residues retained at soil surface) on soil enzymes under different CSA practices using advanced measurements of enzymes through zymography and microdialysis technique.

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