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RESEARCH ARTICLE

Changes in soil nutrient content and enzymatic activity under conventional and zero-tillage practices in an Indian sandy clay loam soil

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Abstract For 3 years we studied the impact of different tillage practices on biological activity, major nutrient transformation potential in a sandy clay loam soil and crop yield in a Himalayan subtemperate region. Field agroecosystems with a rotation of two grain crops per year (lentil-finger millet) received four different tillage practices: zero–zero (ZZ), conventional–conventional (CC), zero–conventional (ZC), and conventional–zero (ZC) tillage. Most of the chemical parameters were influenced by the type of tillage practice. ZZ increased the soil organic carbon (SOC) content in the upper soil layer from 6.8 to 7.5 mg g^{-1} soil. Similarly available N was increased by 6.1% in ZZ over CC. Under zero tillage soil generally had higher P and K content than under other tillage practices. Soil carbohydrate content was also increased from 3.1 to 4.9 mg g^{-1} and dehydrogenase activity was also increased significantly under continuous zero-tillage practice. Alkaline phosphatase, protease, and cellulase were most sensitive to changes due to tillage management. Alkaline phosphatase and protease activity was greater (by 9.3–48.1%) in the zero-tillage system over conventional practice. In contrast, cellulase activity was more (by 31.3–74.6%) in conventional practice than other management practices. We suggest that, by understanding the effects of tillage on soil biological properties, soil quality and agricultural sustainability of subtemperate hill agro-ecosystems may be improved.

Keywords Biological activity · Soil enzymes · Nutrient availability · Zero tillage · Conventional tillage · Soil carbohydrate · Hill agro-ecosystem

Introduction

Sustainability of agricultural systems has become an important issue all over the world. Many issues of sustainability are related to soil quality and its change with time (Karlen et al. 1997). According to Doran and Parkin (1994), soil quality is “the capacity of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health.” Soil biological activities have been suggested as one of the important indicator of soil quality (Dick 1994).

Considerable interest exists in adopting alternate or modification in conventional soil management practices that may reduce soil erosion and leaching losses of soil nutrients. Tillage alters soil structure by exposing more soil organic matter (SOM) to microbial attack, which ultimately destabilize macroaggregates and thus fail to protect and maintain SOM (Beare et al. 1994). Tillage impacts are generally more pronounced in marginal soils and harsh

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environments than in inherently fertile soils of high resilience and favorable micro- and mesoclimates (Lal 1989). Further more, energy costs in no-tillage practice are lower than in conventional management practice using plough or power tiller (Raper et al. 2000).

Soil erosion has been an increasing problem for hill ecosystem. The steep slopes in the Himalayas along with depleted forest cover as well as high seismicity have been major factors in soil erosion (Jain et al. 2001). So, practice of zero-till management will be better proposition for hill farmers not only to restrict erosion but also to save energy for cultivation. Although the effects of tillage on different soil properties have been studied widely, the effects of tillage practices on enzymatic behavior and nutrient transformation have not been extensively studied in hill agroecosystems. The objectives of this study were to determine the soil enzyme activities in a rainfed sandy clay loam soil under four different tillage practices in a hill agro-ecosystem. We hypothesized that untilled soil would stimulate the enzyme activity. We also hypothesized that soil under alternate zero-tillage and conventional tillage practice would behave differently in terms of biological attributes as compared with continuous zero-tillage or conventional tillage practices. The overall aim of the study is to be able to presume the nutrient transformation pattern in the soil of a hill agro-ecosystem under a particular tillage system.

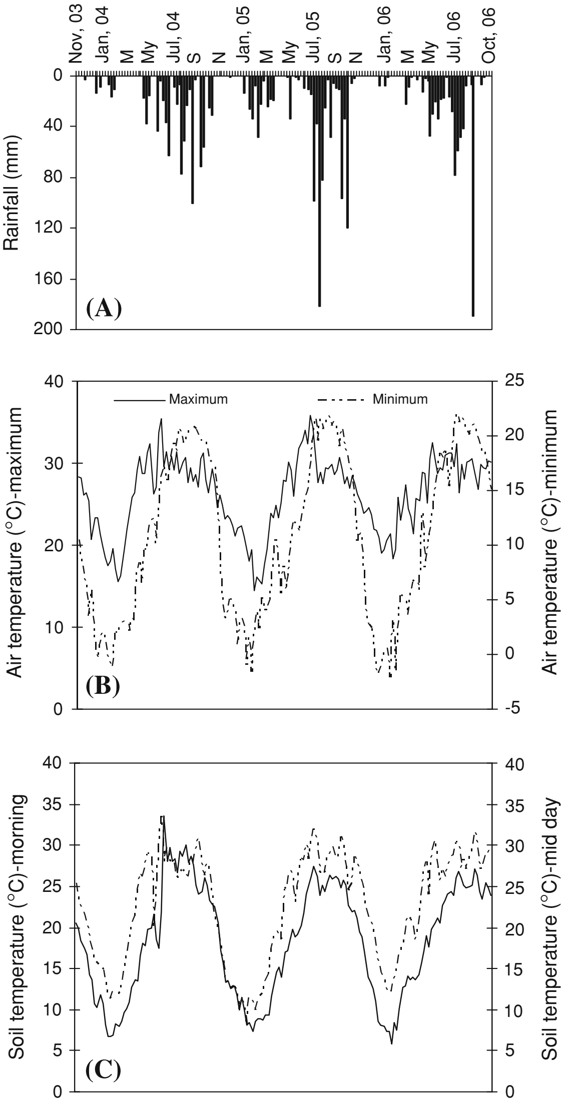

Fig. 1 Weekly total rainfall (**a**), average air temperature (**b**), and soil temperature (**c**) during the total experimental period. M: March; My: May; S: September: N: November

Materials and methods

Experimental details

A field experiment was conducted at the experimental farm of Vivekananda Institute of Hill Agriculture, located in the Indian Himalayan region at Hawalbagh (29° 36′ N and 79° 40′ E, 1,250 m a.s.l), in the state of Uttarakhand, India. The climate is subtemperate, characterized by moderate summer (May–June), extreme winter (December–January), and a general dryness, except for the southwest monsoon season (June–September). The average daily maximum and minimum air temperatures ranged from 18.6°C to 0.6°C in January, and 32.2°C and 18.7°C in June. Weekly rainfall during the experimental period is shown on Fig. 1. The soil of the experimental field was classified as sandy clay loam (21.8% clay, 19.7% silt, and 58.5% sand) and it contains 0.51% oxidizable organic carbon, 305.5 kg ha^{-1} alkaline permanganate oxidizable N, 23.6 kg ha^{-1} Bray's P, and 87 kg ha^{-1}1 N NH$_4$OAc extractable K.

The experiment was initiated during October, 2003 after the harvest of soybean crop. The experiment included two crops in rotation per year, lentil (*Lens esculenta*, variety VL-4; October–April) and finger millet (*Eleusine coracana*, variety VL-149; June–September) in four treatment combinations:

- Conventional tillage practice in both lentil and millet (CC): two ploughings (15–20 cm deep) and one harrowing were done before sowing. Two hand weedings were done to control weeds.
- Conventional tillage in lentil and zero tillage in finger millet (CZ).
- Zero tillage in both crops (ZZ): plots were seeded with a seed drill. Weeds were controlled before sowing with glyphosate [isopropylamine salt of *N*-(phosphonomethyl) glycine; Round up®] at the rate of 3 l ha^{-1}.
- Zero tillage in lentil and conventional tillage in finger millet (ZC).

The four treatments were arranged in a randomized block design replicated six times with plots of 2.6 m × 3.5 m. Fertilizers used were urea for N, single superphosphate for P, and murate of potash for K in finger millet with recommended doses of N, P, and K of 40, 20, and 20 kg ha^{-1} respectively. In lentil, 18 and 46 kg ha^{-1} of N and P, respectively, was applied using diammonium phosphate. Fertilizers were broadcasted in all the four treatments as basal dose in both the crops.

Soil sampling, preparation, and analysis

After harvesting of finger millet, soil samples were taken from the surface layer (0–15 cm) in three replicates in October, 2006 before the start of land management for lentil. Soil samples (100 g) were sieved (2 mm) after removing plant material and roots. Half of the samples were air-dried for 3 days and stored at room temperature until chemical analysis. The rest of the sieved soil (2 mm) was kept at 4°C and then analyzed within 2 weeks. All chemical and microbiological results reported are means of three replicates and are expressed on an oven-dry basis. Soil moisture content was determined after drying at 105°C for 24 h.

Soil pH was measured in a 1:2.5 soil-water suspension (Jackson 1962). Soil was analyzed for oxidizable SOC and soil organic matter by the method of Walkley and Black (1934), for Kjeldahl N by FOSS Tecator (Model 2200), for available P after Bray and Kurtz (1954), and for available K after treatment with 1 N ammonium acetate and estimation using a flame photometer (Jackson 1962).

Soil carbohydrate content was estimated following the method of Martens and Loeffelmann (2002) with some modifications. Soil sample (100 mg) was first solubilized in 14 M H_2SO_4 and then hydrolyzed with 1 M H_2SO_4 to obtain monosaccharides, which were estimated colorimetrically using the phenol–sulfuric acid method (Dubois et al. 1956).

Activity of the following soil enzymes was measured: (a) dehydrogenase, due to its important role in degradation of organic matter and because it is a general indicator of soil enzymatic activity; (b) *β*-glucosidase, due to its critical role in releasing lower-molecular-weight sugars (important energy sources of micro-organisms); (c) cellulase, as an indicator of cellulose degradation; (d) urease and protease, due to their role in releasing of inorganic N in the N turnover; and (e) phosphomonoesterases, for their role in P transformation and turnover.

Soil enzymes were chosen for their definite role in nutrient transformation. Soil dehydrogenase activity was estimated by reducing 2,3,5-triphenyltetrazolium chloride (Casida et al. 1964). Cellulase activity (EC 3.2.1.4) was determined by following the method reported by Schinner and Von Mersi (1990). Glucose equivalent was then estimated following the dinitrosalicylic acid (DNS) method (Miller 1969). *β*-glucosidase activity (EC 3.2.1.2.1) was estimated by determining the amount of *p*-nitrophenol released after 1 h of incubation with *p*-nitrophenyl-*β*-D-glucopyranoside (Eivazi and Tabatabai 1977).

Urease activity (EC 3.5.1.5) and protease activity (EC 3.4.2.21–24) was measured following the methods of Tabatabai (1982) and Ladd and Butler (1972), respectively. Activity of acid and alkaline phosphatase (EC 3.1.3.2 and 3.1.3.1) was determined using the method developed by Tabatabai and Bremner (1969).

Grain yield

Whole plots were harvested in April and September each year for lentil and finger millet, respectively. Lentil and finger millet grain yields were expressed at 14% and 12% moisture basis, respectively. Lentil equivalent yield was calculated based on the minimum support price (MSP) fixed for farmers (CACP, India) in a particular year: Rs. 5,050–5,250 and Rs. 15,000–15,500 Mg^{-1} for finger millet and lentil, respectively.

Statistical analyses

Each sample was analyzed in triplicate and the values were then averaged. Data were assessed by Duncan's multiple range tests (1955) with a probability $P \leq 0.05$. Differences between the mean values were evaluated by a one-way analysis of variance (ANOVA) by using SPSS version 10.0.

Results

Soil pH values of the soils ranged from 5.2 to 5.5 (Table 1) and were significantly higher in ZC than in CZ treatment. Soil pH was highest in ZC and least in CZ treatment. Considerable variations in soil organic C and CHO content was detected. In zero tillage, these values were significantly higher than in other treatments (Table 2). Similarly, CHO–C content and its ratio to SOC and total organic matter were highest in ZZ treatment, while ZC showed the lowest values. SOC accumulation was found in ZZ (significantly higher than in CC), and the lowest in ZC. Soil CHO content was significantly higher in ZZ than in other treatments; on the other hand, no difference was detected among CC, CZ, and ZC treatments (Table 2). A similar trend was found in the ratio of carbohydrate carbon to total organic carbon. ZC was the least in contributing soil carbohydrate to soil organic matter and ZZ contributed the most.

Table 1 Tillage effects on soil pH, organic C, and carbohydrate (CHO) content

Treatment	pH (H_2O)	Org. C (%)	CHO (%)	CHO–C to OC (%)
CC	5.3^{ab}	0.68^{b}	0.31^{a}	17.7
CZ	5.2^{a}	0.73^{bc}	0.29^{a}	16.4
ZC	5.5^{b}	0.56^{a}	0.22^{a}	15.3
ZZ	5.3^{ab}	0.75^{c}	0.49^{b}	26.7

Values in each column sharing the same letter are not significantly different ($P < 0.05$)

CC: conventional–conventional, CZ: conventional–zero till, ZC: zero till–conventional, ZZ: zero till–zero till

Table 2 Effects of different tillage practices on Kjeldahl N, available P, and ammonium-acetate-extractable K content

Treatment	Kjeldahl-N (kg ha^{-1})	Bray's-P (kg ha^{-1})	NH_4OAc-extractable K (kg ha^{-1})
CC	373^{b}	25.4^{a}	93.3^{a}
CZ	352^{a}	26.3^{a}	91.8^{a}
ZC	350^{a}	25.4^{a}	93.9^{a}
ZZ	397^{c}	27.5^{b}	97.8^{b}

Values in each column sharing the same letter are not significantly different ($P < 0.05$)

CC: conventional–conventional, CZ: conventional–zero till, ZC: zero till–conventional, ZZ: zero till–zero till

Available N and P contents were significantly higher in ZZ than in other treatments (Table 2). Extractable K content was higher for ZZ and ZC in comparison with other treatments.

Dehydrogenase activity varied from 1.6 to 2.9 µg 2, 3, 5-triphenylformazan (TPF) produced g^{-1} h^{-1} (Fig. 2) and was significantly higher in zero-tillage as compared to other treatments. Cellulase activity varied from 64.7 to 113.1 mg glucose equivalent g^{-1} 24 h^{-1}, being significantly higher in CC than in other treatments (Fig. 2). The least cellulase activity was detected in ZZ treatment.

β-glucosidase activity also followed a similar pattern, varying from 129 to 136 mg *p*-nitrophenol produced g^{-1} h^{-1} increasing in the order CZ < ZC < ZZ < CC (Fig. 2). Urease activity was close in CC, CZ, and ZZ and the lowest in ZC (Fig. 3). Protease activity ranged from 3.1 to 5.8 µg tyrosine g^{-1} 2 h^{-1} and was significantly higher in ZZ as compared with other treatments. Acid phosphatase activity (Fig. 4) varied from 81 to 89 µg *p*-nitrophenol produced g^{-1} h^{-1} (Fig. 4). Zero-tillage practice resulted in a significantly higher activity than in CC treatment. Alkaline phosphatase activity ranged from 3.7 to 6.9 µg *p*-nitrophenol produced g^{-1} h^{-1} and was significantly higher in ZZ than all other management practices (Fig. 4).

Weather conditions are summarized in Fig. 1. Vegetative growth of lentil occurred from October

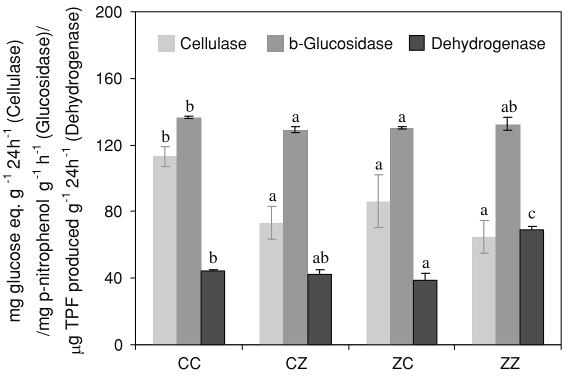

Fig. 2 Dehydrogenase, cellulase, and *β*-glucosidase activities in soil with different tillage practices. Bars sharing the same letter are not significantly different ($P < 0.05$). Error bars represent standard deviation

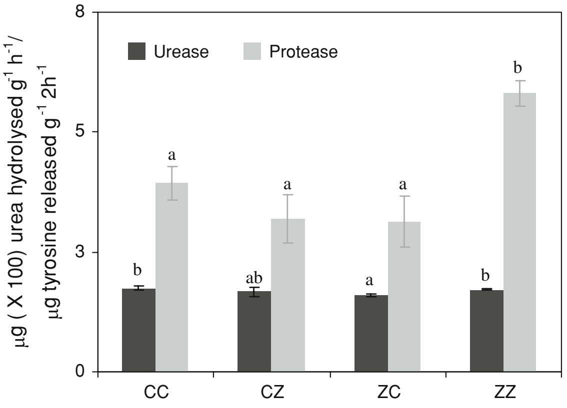

Fig. 3 Urease and protease activities in soil with different tillage practices. Bars sharing the same letter are not significantly different ($P < 0.05$). Error bars represent standard deviation

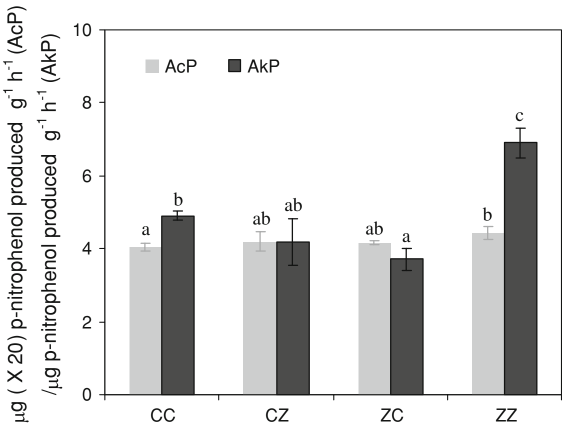

Fig. 4 Acid and alkaline phosphatase activities in soil with different tillage practices. Bars sharing the same letter are not significantly different ($P < 0.05$). Error bars represent standard deviation

until the middle of January, and the reproductive period occurred from the end of January until the end of March. Vegetative growth of finger millet occurred from June until the middle of August and the reproductive period occurred in September. The quantity and distribution of rainfall were highly variable during the experimentation years. The second study year (2004–2005) was almost normal as compared with long-term rainfall conditions, and was characterized by a favorable rainfall during both the growing and reproductive periods of lentil, whereas two other cropping seasons had long drought periods (Fig. 1). A long moisture stress period during lentil growth led to a significant shortening of the grain yield during the first and third years of the experiment (Table 3). There was little rainfall variation during finger millet growing seasons, which was reflected in the yield data. There were no significant effects of tillage practices during the 3 years in either finger millet or lentil yield (Table 3). Lentil and finger millet yield as affected by an interaction between year and tillage is presented in Table 3. The interaction between year and tillage was not significant ($P < 0.05$) for either lentil and finger millet crops.

Table 3 Grain yield of lentil, finger millet, lentil equivalent yield of finger millet (LEY), and total yield as affected by tillage treatments

Source of variation	Yield (Mg ha^{-1})			
	Lentil	Finger millet	LEY	Total
Year (Y)				
2003–04	0.39	3.75	1.26	1.65
2004–05	1.24	3.06	1.03	2.27
2005–06	0.41	2.35	0.80	1.21
$P > F$	<0.01	<0.01	–	<0.01
CV, %	20	13	–	11
Tillage management				
CC	0.71	3.01	1.02	1.73
CZ	0.61	3.00	1.02	1.63
ZC	0.69	2.88	0.97	1.66
ZZ	0.70	3.33	1.12	1.82
$P > F$	NS	<0.01	–	0.02
Interactions ($P > F$)				
Y × T	NS	NS	–	NS

Discussion

Figure 1 shows that rainfall (October–September) varied among the 3 years, being about 760, 1,025, and 720 mm in 2003–2004, 2004–2005, and 2005–2006, respectively. Distribution of rainfall was more prominent during the growth of lentil. In terms of long-term average, the first and third year were characterized by long drought periods. Temperature variation was not observed across years during crop growth.

Though soil biological activity was more or similar under zero-tillage practice as compared with conventional management, no significant differences in grain yield were found either in lentil or in finger millet grain yield across treatments. Bhattacharyya et al. 2008 reported no difference in rice and wheat yield between zero-tillage and conventional tillage management among tillage systems under similar agroclimatic zone of the N–W Himalayas in a 4-year study. However, Lenssen et al. (2007) reported higher lentil yield in conventional tillage practice as compared with zero-tillage practices in a cropping sequence study.

The higher yield of lentil during 2004–2005 was associated with high rainfall during the growth stages of lentil. Total rainfall during the period was 224 mm in 2003–2004 as compared with 56 and 55.7 mm during 2003–2004 and 2005–2006, respectively. Strong correlation was also observed between yield and precipitation during the crop cycle (De vita et al. 2007). Significant yield differences were observed in lentil, finger millet as well as total lentil equivalent yield (Table 3). This might be attributed to variable rainfall across years. No differences were observed in lentil yield when averaged across years, whereas finger millet yield was 0.32 Mg ha^{-1} more under zero-tillage practice than conventional management practice. ZC treatment was lowest in terms of finger millet and CZ was lowest in terms of lentil yield when averaged across years. The year × tillage interactions for both the crops as well as total yield were not significant.

The increase in soil organic matter content in zero-tillage treatment (by 10.3% after 3 years) reflects a reduced rate of leaching in the soil profile in the top soil studied. Loss of C in the soil due to tillage has already been documented (Reicosky 2003). This was further confirmed by the CZ treatment, where short-term breaks in soil disturbance resulted in an increase of SOC content. In relatively undisturbed soil, organic C is mainly contributed by root decomposition and crop residue incorporation (Gale and Camberdella 2000). In ZZ and CZ, higher organic C was mainly contributed by root and crop residue decomposition coupled with lower loss of soil C as compared with CC and ZC, whereas in the latter treatments, due to tillage practice, loss of soil C and pulverization of root and crop residues led to dilution of organic C in soil. The variation in organic C content might be due to the distribution of organic matter within the profile, which is influenced by tillage.

Zero-tillage practice also improved the quality of soil organic matter because soil carbohydrate content was increased significantly in ZZ as compared with conventional tillage practice. An increase in soil CHO content in zero-tillage practice has been reported earlier (Arshad et al. 1990; Kapusta et al. 1996). Soil CHO is an important source of energy for micro-organisms, therefore zero tillage is suggested to promote biological activity in the soil. This was supported by higher dehydrogenase activity and ratio of CHO–C to SOC in zero-tillage as compared with conventional tillage treatments.

A small range and no significant differences between the treatments in topsoil pH were documented (Table 2). In the soil surface, where C was increased due to zero-tillage practice, soil pH did not differ significantly. However, little difference in soil pH in zero-tillage practice was reported in literature as compared with conventional practice (Falatah and Al-Derby 1993; Franzluebbers and Hons 1996; Martin-Rueda et al. 2007).

Differences in available N among tillage systems are in agreement with other studies (Martin-Rueda et al. 2007). Available N was significantly higher in ZZ than in other treatments. Similarly, in a 25-year-long study on Mollisols in Nebraska, organic C, and organic N were significantly greater under zero-tillage than conventional tillage in the 0–5 cm soil layer (Six et al. 1998). In another study, soil N content was also significantly increased under zero or minimum tillage (Martin-Rueda et al. 2007). Soil N tends to react faster than C to tillage practices in a subtemperate soil. This result is consistent with the report by Green et al. 2007. Under conventional tillage loss of soil N could have been caused by nitrate leaching. Higher available N in ZZ may be attributed to less loss through immobilization, volatilization, denitrification, and leaching (Malhi et al. 2001), whereas alternate tillage practice and no disturbance of soil might lead to more loss of N through different mechanism.

Phosphorous and potassium were higher in the topsoil under zero-tillage practice due to probably higher SOC level and to surface applied K and P fertilizers (Franzluebbers and Hons 1996). Zibilske et al. (2002) reported that improvement of soil available P was due to redistribution or mining of P at lower soil depths. Increase in K content in the upper 15 cm untilled soil was consistent with the report by Martin-Rueda et al. (2007).

Enzyme activities were generally higher in zero-tillage practice than in conventional managed plots except for enzymes related to C turnover as well as urease. This result is in agreement with Dick et al. (1997). It was reported that urease activity was more in zero-tillage practice soils, though our result showed no difference. Zero tillage practice led to significantly higher dehydrogenase activity. This result is confirmed by the higher carbohydrate-C and its proportions per unit of organic C in ZZ treatment (Table 1). Nannipieri 1994 also concluded that more dehydrogenase activity in zero-till soil was due to larger proportions of microbial biomass and carbohydrate-C per unit of organic C.

Cellulase and β-glucosidase activities were significantly influenced by tillage management in the upper soil layer. Cellulase activity was significantly higher in conventional than in untilled soil. CC resulted in a significant increase in cellulase activity than all other treatments. Least cellulase activity was detected in ZZ treatment. This result is in contrast with all other previous results (Balota et al. 2004). This may be due to the fact that the cited study utilized ultisols in Brazil, which are very low in organic matter (OM). Our result is consistent with previous study by Corlay-Chee et al. (2001), whose comparison of microbial activity of two soils (0–5 cm), one with conventional and one with conservation tillage, showed that all microbial groups except cellulose decomposers decreased in conventional tillage during the same time span.

β-glucosidase activity was also greater in conventionally managed soil than ZC and CZ treatments. These results are in contrast with most of the earlier reports (Green et al. 2007). Interestingly, our result is consistent with previous study by Corlay-Chee et al. 2001, who reported that there was no significant difference between tillage practices on β-glucosidase activity at 5–15 cm soil depth, though the activity was greater in zero-tillage practice at 0–5 cm depth (De la Horra et al. 2003).

Acid and alkaline phosphatase activities were significantly higher in zero-tillage than in conventional tillage treatments. ZC and CZ treatments were lower than the other two treatments. Short-term zero-tillage (CZ) practice leads to slight increase in phosphatase activity as compared with short-term conventional practice (ZC). The increase in activity of hydrolase enzymes might be due to higher levels of intracellular and/or extracellular enzymes, immobilized by recalcitrant humic moieties (Nannipieri 1994). Acid phosphatase activity was recorded during the winter season and it will be greater in the summer months as its activity is temperature dependent. Kramer and Green (2000) also reported that phosphatase activity was 2.4 times greater in summer than in winter. Soil temperature does influence most enzyme activities (Katterer et al. 1998; Trevors 1984).

The differential accumulation of organic C, N, and inorganic nutrients in topsoils under different tillage practices as well as accumulation of inorganic nutrients tends to increase soil enzymatic activities (Dick et al. 1997). The biochemical environments of differently tilled soils are having differential oxidative potential and it is less oxidative in zero-tillage soil than conventional tillage practices, as dehydrogenase activity is higher in zero-tillage treatment.

Conclusions

Three years continuous management practice on a sandy clay loam soil in a subtemperate region of the Indian Himalayas improved the quality of soil organic matter and promoted soil enzymatic activities. It is suggested that zero-tillage practice may be successful in maintaining sustainability and improving soil biological properties, in hill agro-ecosystems. However alternate zero and conventional tillage management neither improved soil nutrient status nor enzymatic activity.

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