Agroforest Syst (2012) 84:311–323
DOI 10.1007/s10457-011-9454-8

Soil quality indicator responses to row crop, grazed pasture, and agroforestry buffer management

Bodh R. Paudel · Ranjith P. Udawatta · Robert J. Kremer · Stephen H. Anderson

Received: 16 May 2011 / Accepted: 31 October 2011 / Published online: 13 November 2011
© Springer Science+Business Media B.V. 2011

Abstract Soil enzyme activities and water stable aggregates have been identified as sensitive soil quality indicators, but few studies exist comparing those parameters within buffers, grazed pastures and row-crop systems. Our objective was to examine the effects of these land uses on the activities of selected enzymes (β-glucosidase, β-glucosaminidase, fluorescein diacetate (FDA) hydrolase, and dehydrogenase), proportion of water stable aggregates (WSA), soil organic carbon and total nitrogen content. Four management treatments [grazed pasture (GP), agroforestry buffer (AgB), grass buffer (GB) and row crop (RC)] were sampled in 2009 and 2010 at two depths (0 to 10- and 10 to 20-cm) and analyzed. Most of the soil quality indicators were significantly greater under perennial vegetation when compared to row crop treatments. Although there were numerical variations, soil quality response trends were consistent between years. The β-glucosaminidase activity increased slightly from 156 to 177 μg PNP g^{-1} dry soil while β-glucosidase activity slightly decreased from 248 to 237 μg PNP g^{-1} dry soil in GB treatment during 2 years. The surface (0–10 cm depth) had greater enzyme activities and WSA than sub-surface (10–20 cm) samples. WSA increased from 178 to 314 g kg^{-1} in row crop areas while all other treatments had similar values during the 2 year study. The treatment by depth interaction was significant ($P < 0.05$) for β-glucosidase and β-glucosaminidase enzymes in 2009 and for dehydrogenase and β-glucosaminidase in 2010. Soil enzyme activities were significantly correlated with soil organic carbon content ($r \geq 0.94$, $P < 0.0001$). This is important because soil enzyme activities and microbial biomass can be enhanced by perennial vegetation and thus improve several other soil quality parameters. These results also support the hypothesis that positive interactions among management practices, soil biota and subsequent environmental quality effects are of great agricultural and ecological importance.

Keywords Agroecosystem interactions · Microbial activity · Perennial vegetation · Soil enzymes · Soil organic carbon

B. R. Paudel (✉)
Department of Crop and Soil Sciences, Washington State University, Johnson Hall, Pullman, WA 99164, USA
e-mail: bodh.paudel@wsu.edu

R. P. Udawatta · S. H. Anderson
Department of Soil, Environmental and Atmospheric Sciences, University of Missouri, 302 Anheuser-Busch Natural Resources Building, Columbia, MO 65211, USA

R. P. Udawatta
Center for Agroforestry, University of Missouri, 203 Anheuser-Busch Natural Resources Building, Columbia, MO 65211, USA

R. J. Kremer
USDA-ARS Cropping Systems and Water Quality Unit, University of Missouri, Columbia, MO 65211, USA

Introduction

Interactions between soil biological parameters, management practices and subsequent environmental quality effects are of great agricultural and ecological significance (Watt et al. 2006). However, despite the important roles of the soil microbiota in agroecosystem functions (Verhoef and Brussaard 1990), very little is known of their activities, composition, and abundance under grazing pasture systems. Changes in microbial community structure, biomass and activity rates vary with the severity and duration of disturbance (Schloter et al. 2003), although overall, the sustainability of any land management system depends on the diversity of the soil microbial community and their biochemical processes (Pankhurst et al. 1996). Microbial and biochemical soil properties have been suggested as early indicators of changes in soil quality. A better understanding of how to manipulate environmental conditions to fully utilize the microbial potential will help developing more sustainable systems, including those used for agroforestry.

Agroforestry is an intensive land management practice that optimizes economic and environmental benefits from biophysical interactions by deliberately incorporating trees and/or shrubs with crops and/or livestock in spatial or temporal arrangements (Gold and Garrett 2009). Agroforestry buffers can help reduce nonpoint source pollution from row crop areas by improving soil hydraulic properties and reducing surface runoff (Udawatta et al. 2002; Lovell and Sullivan 2006; Kumar et al. 2008). Agroforestry buffers have also been shown to increase soil organic carbon (SOC) through litter accumulation and root activity (Young 1989), reduce soil erosion (Escobar et al. 2002; Schultz et al. 2004) and increase productivity (Noble et al. 1998).

Silvopasture is a type of agroforestry management that is believed to provide environmental, economical and social benefits. Tree or tree-grass buffers are used in these systems to protect water resources by restricting animal access. Within silvopastures, grazing and stocking rates affect the animals, nutrient utilization, and soil microbial activities and thereby affecting the ecology of pasture soils (Haynes and Williams 1993; Sigua 2003). The extent to which soil quality indicator properties can change within a season or due to the type of pasture management is of interest from several viewpoints, including the hypothesis that incorporation of agroforestry into pastures has good potential for improving soil quality.

Soil quality is defined by Doran and Parkin (1994) as the capacity of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health. Soil quality assessment is a process by which soil resources are evaluated on the basis of soil functions (Weil and Magdoff 2004). Soil quality assessment involves measurement of multiple soil parameters representing chemical, physical, and biological characteristics (Doran and Parkin 1994). Periodic assessments of soil quality with known indicators and thresholds help to assess the capacity of land for a particular function. Selection of soil quality indicators depend on soil characteristics, land use and management goals, and environmental protection (Stott et al. 2010).

Enzyme activities are recognized as possible indicators of the changes in soil management. The activities are believed to indicate early responses to changes in management practices (Dick 1994; Bandick and Dick 1999). Soil enzymes play key biochemical functions in the overall process of organic matter decomposition in the soil system (Burns 1983; Sinsabaugh et al. 1991). However, the natural variation within and among soils is the major constraint (Trasar-Cepeda et al. 2000). Possibly due to this reason, studies have often stated that results obtained for a particular soil cannot be generalized due to differences in their inherent soil properties (Gianfreda et al. 2005; Bielinska and Pranagal 2007). A number of observations may be required to determine variability in space and time, but it may also be possible to develop specific measures of functional diversity by quantifying differences in soil enzyme activities.

Information on grazing systems with agroforestry and grass buffer interactions within the temperate agroforestry zone on soil quality and conservation is limited; therefore research designed to explore new species and management combinations are necessary to quantify the sustainability of those systems (Jose et al. 2004). To ensure that grazing pasture systems with agroforestry practices improve soil functioning and environmental quality, soil quality assessment can be used to provide information needed to evaluate the impact of implementing these management practices (Andrews et al. 2004). Furthermore, a better understanding of overall microbial activity and carbon

dynamics in an agroforestry practice will contribute to estimates of environmental and economic benefits and assist policy and management decisions for these practices (Lee and Jose 2003). Our objectives were to evaluate the effects of agroforestry and grass buffers on soil parameters in grazed pasture and row-crop systems and to compare the temporal variation in those parameters. We hypothesized that there is an effect of grazed pasture with buffers and row-crop management on soil quality parameters and that parameter values vary annually due to variation in soil characteristics.

Materials and methods

Study area

The study was carried out at the Horticulture and Agroforestry Research Center (HARC) of the University of Missouri in New Franklin, MO (92°74′W and 37°2′N; 195 m above sea level). Four small (~0.8 ha), replicated grazed pasture (GP) watersheds with agroforestry buffers (AgB; tree-grass buffers) and grass buffers (GB) were evaluated. The GP area was divided into six paddocks where cattle were introduced in 2005 and rotationally grazed (Kumar et al. 2008). The land was under tall fescue grass (*Festuca arundinacea* Schreb.) without grazing before establishment of the watersheds. The GB buffer areas were reseeded with tall fescue (*Festuca arundinacea*; Kentucky 31) in 2000 and the pastures were seeded with red clover (*Trifolium pratense* L.) and lespedeza (*Kummerowia stipulacea* L.) in 2003. The AgB buffers consisted of eastern cottonwood trees (*Populus deltoides* Bortr. ex Marsh.). Soils for the row-crop (RC) treatment were sampled from an adjacent field located just north of the pasture areas. The crop was corn in 2009 and soybean in 2010, with conventional tillage. Soils at the study site were classified as Menfro silt loam (fine-silty, mixed, superactive, mesic Typic Hapludalfs).

Experimental design and sampling

The management treatments were GP, AgB, GB, and RC. The AgB and GB treatments were in the buffer areas of the small watersheds with respective buffer type and the GP treatment was in the rotationally grazed area in the watersheds. The experimental design was completely randomized with a split plot for two soil depths (0 to 10- and 10 to 20-cm).

Soil samples were collected in June in 2009 and 2010 from each of two treatment replications and from three sampling positions per treatment plot (i.e., six sample locations per treatment). For GP and RC treatments, samples were taken only from the middle landscape positions. Soil samples for the GB treatment were taken from the center of the buffer, while those from the AgB treatment were taken about 40 cm from the base of a tree trunk. In 2010, 48 core samples were also collected to determine bulk density for both depth increments within all treatments. Water stable aggregate and enzyme samples were collected with a soil auger, placed in labeled plastic bags, sealed and transported to the laboratory in a cooler. All samples were maintained at their field moist condition and stored at 4°C until analyzed.

Laboratory analyses

A 10-g air-dried soil sample was used to measure water stable aggregates using the wet-sieving method for aggregates >250 μm diameter (Angers and Mehuys 1993). The aggregate content was adjusted for soil moisture and expressed on an oven-dry weight basis. Soil bulk density was determined by the core method (Blake and Hartge 1986). Soil organic carbon (SOC) and total nitrogen (TN) contents were determined following the methodology of Nelson and Sommers (1996) on a LECO TruSpec CN Analyzer with dry combustion at 950°C.

All soil enzymes were colorimetrically quantified in laboratory assays. β-Glucosidase enzyme activity was determined based on the procedure of Dick et al. (1996). The method was based on colorimetric determination of *p*-nitrophenol (PNP) released by the substrate with 1-g sieved moist soil samples incubated with buffered (pH 6.0) *p*-nitrophenol-β-D-glucoside. Soil was incubated with the *p*-nitrophenyl-β-D-glucoside substrate for 1 h at pH 6.0 at 37°C. A predeveloped calibration equation was used to calculate the concentration of p-nitrophenol colorimetrically (410 nm) and the enzyme activity was expressed in μg *p*-nitrophenol released g^{-1} dry soil. β-glucosaminidase enzyme activity was determined according to Parham and Deng (2000). Soil was incubated with the *p*-nitrophenyl-*N*-acetyl-β-D-glucosaminide substrate for 1 h at 37°C. A regression equation developed with

standards was used to determine the concentration of *p*-nitrophenol released colorimetrically (405 nm) and the enzymatic activity was expressed in μg *p*-nitrophenol released g^{-1} dry soil.

Fluorescein diacetate (FDA) hydrolase was colorimetrically quantified at 490 nm (Dick et al. 1996). A sieved 1-g moist soil sample was shaken for 15 min with 20 ml of sodium phosphate buffer and subsequently shaken with 100 μl of 4.8 mM of FDA for 105 min. The absorbance was measured on the filtrate after acetone hydrolysis. A standard calibration curve was used to measure the concentration which was expressed in μg fluorescein released g^{-1} dry soil.

Dehydrogenase enzyme activity was determined as described by Tabatabai (1994) using 6 g of moist soil sample. Soil was incubated with 2, 3, 5-triphenyltetrazolium chloride substrate at 37°C for 24 h. A standard curve was used to calculate the concentration of triphenyl formazan (TPF) product colorimetrically at 485 nm. The enzyme activity was calculated in μg TPF released g^{-1} dry soil.

The water stable aggregates (WSA) and enzyme activities were analyzed in duplicate for each sample.

Statistical analyses

The data were analyzed as a completely randomized design with a split plot for soil depth using Proc GLM in Statistical Software Package SAS version 9.2 (SAS 2008). Data collected in each of 2 years were analyzed separately to determine the treatment effects and the interactions with depth. The parameters measured were analyzed taking into account the four management treatments and two depths. The main effects consisted of treatment effects (management) and the subplot consisted of depth effects. The least significant difference tests (Duncan's LSD) were used for pairwise comparisons of treatment means. Differences were declared significant at the 5% level of significance ($P \leq 0.05$).

Results

Water stable aggregates (WSA)

Water stable aggregates (WSA) ranged from 178 to 705 g kg^{-1} in 2009 and from 314 to 655 g kg^{-1} in 2010 for the various treatments. The RC treatment had the lowest WSA level (178 and 314 g kg^{-1}) and was significantly lower than all other treatments in both years (Tables 1, 2). The GB treatment had the highest WSA percentage (705 and 655 g kg^{-1}) in both years. Variation in WSA levels within perennial vegetation treatments for the 2 years was not significant, but the variation for the RC treatment was much higher than for the other treatments. The amount of WSA was almost double in the second year compared to the first year within the RC treatment probably reflecting the impact of the corn crop in 2009. The differences among the AgB, GB, and GP treatments were not significant in the first year. In the second year, the variation of WSA between AgB and GP was not significant and both the treatments showed significantly lower WSA than the GB treatment. There were significant depth effects in both years (Tables 3, 4; Fig. 1).

Soil bulk density

Bulk density was estimated only in 2010 with differences among the treatments being non-significant, even though the row crop treatment had the highest value (1.42 g cm^{-3}) and AgB had the lowest value

Table 1 Water stable aggregates (WSA), soil organic carbon (SOC), Total Nitrogen (TN), *β*-glucosaminidase (GS), *β*-glucosidase (GC), dehydrogenase (DH) and Fluorescein Diacetate (FDA) hydrolase enzyme activities for grazed pasture (GP), agroforestry buffer (AgB), grass buffer (GB) and row crop (RC) treatments (year 2009, $n = 12$)

Treatment	WSA (g kg^{-1})	SOC (g kg^{-1})	TN (g kg^{-1})	GS (μg g^{-1} dry soil)	GC (μg g^{-1} dry soil)	DH (μg g^{-1} dry soil)	FDA (μg g^{-1} dry soil)
GP	613a	18a	2.0a	159a	243a	226a	97a
AgB	686a	17a	2.0a	153a	238a	63ab	986a
GB	705a	17a	1.9a	156a	248a	89ab	828a
RC	178b	12b	1.3b	74b	123b	62b	749a

Data followed by the same letter within a column were not significantly different at $P \leq 0.05$

Table 2 Water stable aggregates (WSA), bulk density (Db), soil organic carbon (SOC), Total Nitrogen (TN), β-glucosaminidase (GS), β-glucosidase (GC), dehydrogenase (DH) and Fluorescein Diacetate (FDA) hydrolase enzyme activities for grazed pasture (GP), agroforestry buffer (AgB), grass buffer (GB) and row crop (RC) treatments (year 2010, $n = 12$)

Treatment	WSA (g kg^{-1})	SOC (g kg^{-1})	TN (g kg^{-1})	Db (g cm^{-3})	GS (μg g^{-1} dry soil)	GC (μg g^{-1} dry soil)	DH (μg g^{-1} dry soil)	FDA (μg g^{-1} dry soil)
GP	556b	16.0a	1.8a	1.38a	171a	241a	324a	760ab
AgB	592b	19.2a	2.2a	1.31a	167a	246a	310a	805ab
GB	655a	18.8a	2.0a	1.32a	177a	237a	338a	811a
RC	314c	12.6a	1.6a	1.42a	92b	165b	175b	705b

Data followed by the same letter within a column were not significantly different at $P \leq 0.05$

Table 3 Variation of water stable aggregates and enzymes activities with depth for agroforestry buffer (AgB), grass buffer (GB), grazed pasture (GP) and row crop (RC) treatments (year 2009)

Treatment	Depth (cm)	WSA (g kg^{-1})	FDA (μg g^{-1} dry soil)	Dehydrogenase (μg g^{-1} dry soil)	β-glucosidase (μg g^{-1} dry soil)	β-glucosaminidase (μg g^{-1} dry soil)
GP	0–10	697a	1146a	300a	310a	210a
	10–20	529b	849b	151b	176b	107b
AgB	0–10	783a	1186a	235a	328a	209a
	10–20	589b	786b	91b	149b	97b
GB	0–10	784a	995a	137a	322a	221a
	10–20	641b	661b	41b	174b	90b
RC	0–10	240a	897a	77a	146a	88a
	10–20	119b	601b	48b	99b	60b

Data followed by different letters within a column within a treatment were significantly different at $P \leq 0.05$

Table 4 Variation of water stable aggregates and enzymes activities with depth for agroforestry buffer (AgB), grass buffer (GB), grazed pasture (GP) and row crop (RC) treatments (year 2010)

Treatment	Depth (cm)	WSA (g kg^{-1})	FDA (μg g^{-1} dry soil)	Dehydrogenase (μg g^{-1} dry soil)	β-glucosidase (μg g^{-1} dry soil)	β-glucosaminidase (μg g^{-1} dry soil)
GP	0–10	680a	935a	452a	324a	235a
	10–20	430b	584b	196b	157b	107b
AgB	0–10	714a	1006a	416a	342a	230a
	10–20	470b	603b	204b	150b	104b
GB	0–10	762a	1005a	472a	319a	247a
	10–20	550b	618b	204b	154b	107b
RC	0–10	400a	931a	213a	199a	107a
	10–20	230b	480b	136b	132b	78b

Data followed by different letters within a column within a treatment were significantly different at $P \leq 0.05$

(1.31 g cm^{-3}; Table 2). Overall, the bulk density values decreased in the order RC > GP > GB > AgB. Although there were no statistically significant differences, perhaps because we had only two treatment replications, the values trended in expected ways, including having significant depth effects (Fig. 2).

Soil carbon and nitrogen

Soil organic carbon (SOC) and total nitrogen (TN) contents varied slightly between the 2 years. In 2009, the SOC and TN concentrations were significantly higher in perennial vegetation treatments compared to

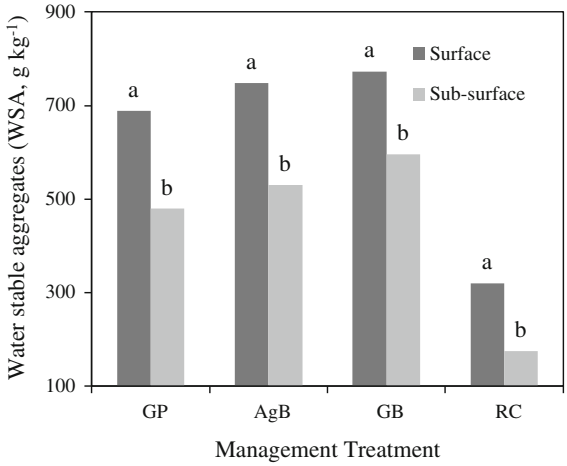

Fig. 1 Water stable aggregate proportions (WSA) for the grazed pasture (GP), agroforestry buffer (AgB), grass buffer (GB) and row crop (RC) management treatments. Samples were from the 0 to 20 cm soil depth and data presented were the average of sampling years, 2009 and 2010

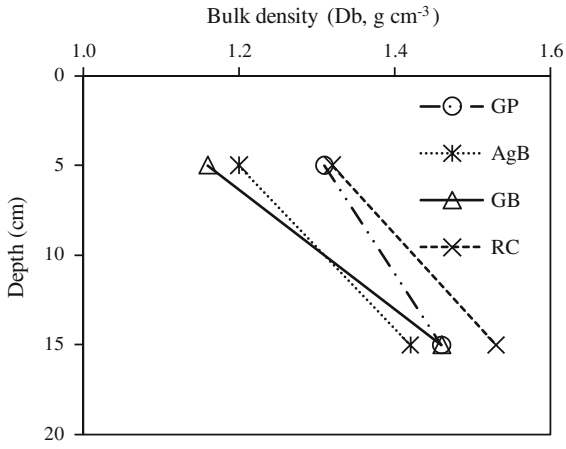

Fig. 2 Soil bulk density as a function of depth for the four study treatments, grazed pasture (GP), agroforestry buffer (AgB), grass buffer (GB), and row crop (RC). Samples were from the 0 to 10 and 10 to 20 cm soil depths and sampling was done in 2010

RC treatment (Table 1), but the differences were not significant in 2010 (Table 2). There was a slight decrease in SOC content (18–16 g kg^{-1}) and TN content (2.0–1.8 g kg^{-1}) in the GP treatment, but the buffer treatments showed slightly higher concentrations in 2010. In the AgB treatment, SOC content increased from 17.0 to 19.1 g kg^{-1} and TN content increased from 2.0 to2.2 g kg^{-1}. In the GB treatment, SOC content changed from 17.0 to 18.8 g kg^{-1} while the TN content changed from 1.9 to 2.0 g kg^{-1}. Soil

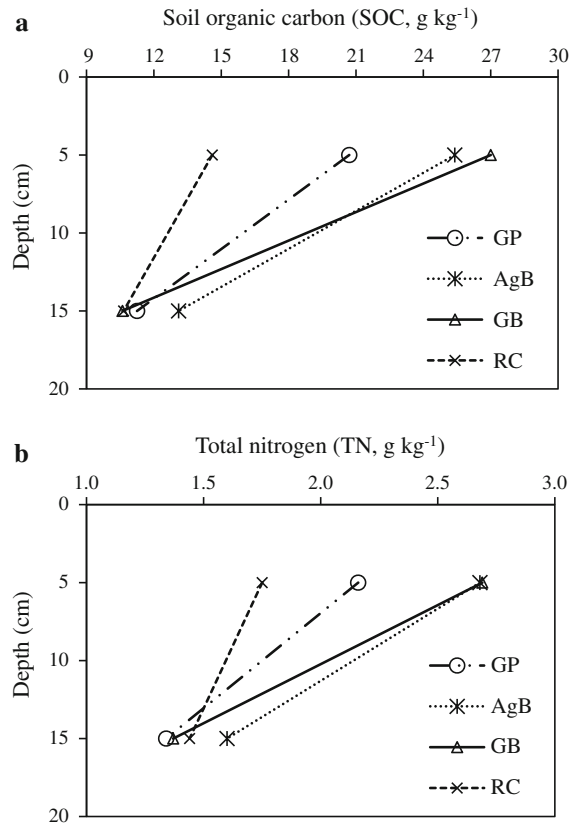

Fig. 3 Soil organic carbon (**a**) and total nitrogen (**b**) as a function of depth for the four study treatments, grazed pasture (GP), agroforestry buffer (AgB), grass buffer (GB), and row crop (RC) for the year 2010. Samples were from the 0 to 10 and 10 to 20 cm soil depths

organic carbon and TN contents in the RC treatment increased from 12.0 to 13.6 and TN increased from 1.3 to 1.6 g kg^{-1}, respectively. There were significant depth effects in SOC and TN (Fig. 3a, b). The perennial vegetation treatments showed a greater decrease in SOC and TN contents from surface to sub-surface compared to row crop agriculture.

Enzyme activities

β-glucosidase and β-glucosaminidase enzyme activities

Analysis of *β*-glucosidase and *β*-glucosaminidase activity revealed significant differences between the RC and all other treatments each year (Tables 1, 2). The *β*-glucosidase activities were very similar in 2009 and 2010 in the GP treatment (243 and 241 μg PNP

g^{-1} dry soil, respectively). For the AgB treatment, β-glucosidase activity slightly increased from 238 to 246 μg PNP g^{-1} dry soil over the 2 years. Similarly for the GB treatment, β-glucosidase activity decreased slightly from 248 to 237 μg PNP g^{-1} dry soil during 2 years. However, the year to year variation in β-glucosidase activity in the RC treatment was greater (123 vs. 165 μg PNP g^{-1} dry soil, respectively).

There were comparatively higher activities of β-glucosaminidase enzyme in the second year than first year for all treatments. The GP treatment showed β-glucosaminidase enzyme activity of 159 μg PNP g^{-1} dry soil in 2009, while in 2010, it was 171 μg PNP g^{-1} dry soil. The β-glucosaminidase enzyme activity increased from 153 to 167 μg PNP g^{-1} dry soil in the AgB treatment and whereas in the GB treatment, the activity increased from 156 to 177 μg PNP g^{-1} dry soil. The RC treatment increased by 18 μg PNP g^{-1} dry soil from 74 in 2009 to 92 μg PNP g^{-1} dry soil in 2010. Among all treatments and years, the RC treatment had the lowest activities.

The treatment by depth interaction was significant for β-glucosaminidase enzyme in both years while the interaction for β-glucosidase enzyme activity was significant only in 2009 (Figs. 4, 5a, b).

Flurorescein diacetate (FDA) hydrolase activity

Higher variability in FDA activities was observed during the 2-year study compared to other enzymes. The FDA activity decreased in all treatments except the GB treatment in 2010 compared to 2009. In the GP treatment, the activity decreased from 997 μg fluorescein g^{-1} dry soil in 2009 to 760 μg fluorescein g^{-1} dry soil in 2010. Similarly, the AgB treatment showed FDA activity of 986 and 805 μg fluorescein g^{-1} dry soil in 2009 and 2010, respectively. The GB treatment showed similar FDA activity during the 2 years (806 and 811 μg fluorescein g^{-1} dry soil in 2009 and 2010, respectively). The RC treatment had an FDA activity of 749 μg fluorescein g^{-1} dry soil in 2009 whereas it reduced to 705 μg fluorescein g^{-1} dry soil in 2010. The FDA hydrolase activity was not significant among treatments in 2009 (Table 1). In contrast, management treatment significantly affected activity in 2010. The RC treatment was not significantly different as compared to the GP and AgB treatments but was significantly lower compared to the GB treatment in 2010

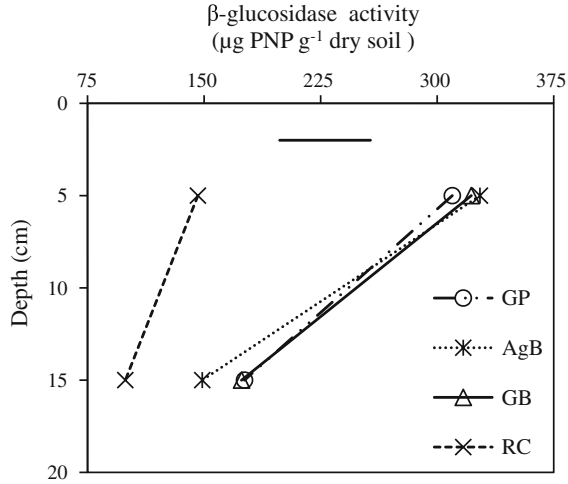

Fig. 4 β-glucosidase enzyme activity as a function of depth for the four study treatments, grazed pasture (GP), agroforestry buffer (AgB), grass buffer (GB), and row crop (RC) for the year 2009. Samples were from the 0 to 10 and 10 to 20 cm soil depths. The *bar* indicates the LSD value (58.3)

(Table 2). The differences in activities among the perennial vegetation treatments were not significant.

Dehydrogenase enzyme activity

Dehydrogenase activities differed significantly in both years among treatments (Tables 1, 2). In 2009, the GP treatment revealed significantly greater activity compared to the RC treatment but the variations among buffers and pasture treatments was not significant. In 2010, all perennial vegetation treatments showed significantly higher activity than the RC treatment (Table 2). Variations in dehydrogenase activities were greater among years for this enzyme compared to the other enzymes studied. In fact, the activities were higher in 2010 compared to 2009 for all treatments. The dehydrogenase activity in the GP treatment increased from 226 μg TPF g^{-1} dry soil in 2009 to 324 μg TPF g^{-1} dry soil. In the AgB treatment, the dehydrogenase activity was 161 μg TPF g^{-1} dry soil in 2009 and 310 μg TPF g^{-1} dry soil in 2010. The GB treatment showed the greatest difference between the 2 years. It increased from 84 μg TPF g^{-1} dry soil in 2009 to 338 μg TPF g^{-1} dry soil in 2010. The activity also increased from 62 μg TPF g^{-1} dry soil to 174 μg TPF g^{-1} dry soil in 2010 for the RC treatment.

The depth effect was significant for all enzyme activities in both years (Tables 3, 4). There were no

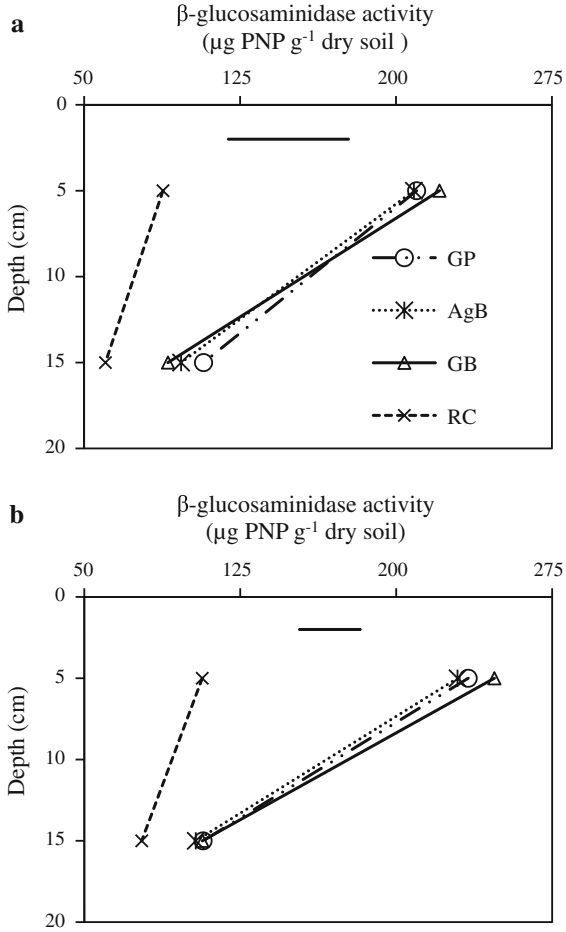

Fig. 5 *β*-glucosaminidase enzyme activity as a function of depth in 2009 (**a**) and 2010 (**b**) for the four study treatments, grazed pasture (GP), agroforestry buffer (AgB), grass buffer (GB), and row crop (RC) for the year 2009. Samples were from the 0 to 10 and 10 to 20 cm soil depth. The *bar* indicates the LSD value (57.7 and 29.2, respectively)

significant treatment by depth interactions in 2009; however, these interactions were significant in 2010 (Fig. 6). The difference in activities between the surface and sub-surface soil was significant for both years.

Discussion

Water stable aggregates (WSA)

The results showed that WSA percentages within soils under RC management were significantly lower as compared to the GP, AgB, and GB treatments which

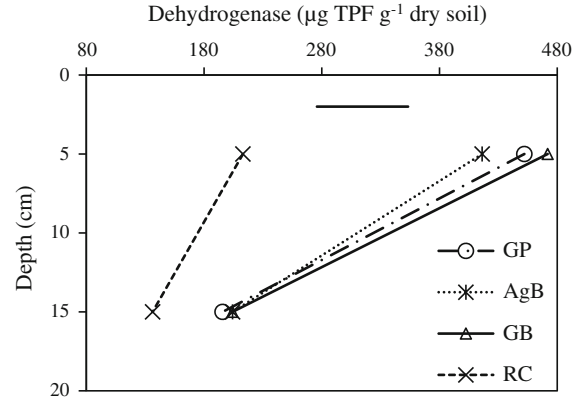

Fig. 6 Dehydrogenase enzyme activity as a function of depth for the four study treatments, grazed pasture (GP), agroforestry buffer (AgB), grass buffer (GB), and row crop (RC) for the year 2010. Samples were from the 0 to 20 cm soil depth. The *bar* indicates the LSD value (77.3)

closely parallel previous findings. Studies frequently show that water stable aggregates in natural grassland, agroforestry, prairies, and managed natural vegetation are significantly higher compared to cultivated areas with row crop management (Kremer and Li 2003; Mungai et al. 2005; Udawatta et al. 2008, 2009; Guo et al. 2010; Kremer and Kussman 2011). The greater aggregate stability was attributed to the increased stabilization of carbon and nitrogen mediated by higher microbial activity and permanent root biomass associated with perennial vegetation while the lower WSA in the cultivated areas was attributed to carbon losses and disturbance in the soil structure associated with prolonged cultivation practices.

Soil organic matter and biological activity in soil highly affect water stable aggregates. Soil organisms are concentrated in litter, around roots, and surface of aggregates where organic matter is available (Ingham 2000). Organic glues resulting from biological decomposition of organic matter bind soil particles to each other and stabilize WSA (Tisdall and Oades 1982). Research indicates that complex polysaccharide molecules are more important in promoting aggregate stability than lighter, simpler molecules (Elliott and Lynch 1984). In the RC treatment, physical disturbance and tillage operations accelerate organic matter decomposition, and destroy fungal hyphae and soil aggregates (Frey et al. 2003; Green et al. 2005). Long-term cropping practices decrease the length and mass of fine roots and deplete soil organic matter resulting

in a reduction of macro-aggregates (Tisdall and Oades 1980; Cambardella and Elliott 1992).

In contrast, perennial vegetation systems improve soil aggregation and organic matter accumulation (Franzluebbers et al. 2000). Grass can act as a cover crop, improve particulate organic matter content, and aggregation by providing continuous grass and root residues (Franzluebbers and Stuedemann 2005; Handayani et al. 2008). The carbon inputs, root penetration and morphology, as well as mycorrhizal association affect aggregation (Denef et al. 2002). In addition, grassland soils are known for high levels of organic matter and greater structural stability (van Veen and Paul 1981).

The reason behind lower aggregate stability in the GP treatment compared to GB could be due to disturbance on the soil surface by grazing animals, unfavorable effects on aggregate stability, and low organic matter input (Bird et al. 2007). Grazing causes soil to break apart, and exposes the organic matter to degradation. Although rotational grazing is more likely to increase aggregate stability (NRCS 2001), heavy grazing disrupts the formation of aggregates. Due to differences in management, species composition, and disturbance, WSA in the GP treatment was comparatively lower among perennial vegetation treatments but significantly higher than the RC treatment.

Also, the bulk density for the RC treatment was found to be 1.42 g cm^{-3} as compared to the average bulk density of 1.33 g cm^{-3} in buffers and grazing areas. This supports our results showing the highest WSA in GB and the lowest in the RC treatment. The bulk density values were not significantly different among treatments probably due to low replication (only two replicates). Kremer and Li (2003) also found that soils under grass vegetation held greater organic matter and had a higher proportion of WSA when compared with traditionally cropped areas.

Soil carbon and nitrogen

The soil organic matter pools (C and N) were affected by management practices. The SOC and TN contents were significantly greater in perennial vegetation treatments compared to row crop systems in 2009. The higher root activity, microbial decomposition and continuous vegetative cover might have contributed greater carbon and nitrogen accumulation compared to row crop where tillage and cultivation practices caused losses of carbon and nitrogen. Greater WSA levels also lead to accumulation of soil organic matter within macroaggregates and protect soil carbon from faunal action and microbial consumption (Beare et al. 1994; Six et al. 2000). Variations in plant biomass and morphology can also cause the variation in nitrogen accumulation in soil (Clement and Williams 1967). According to Lal (2002), conventional tillage can deplete soil organic matter as a result of accelerated mineralization, leaching and translocation. As organic matter increases, soil biological activity increases. This enhances the diversity of organisms and the ecosystem functions they perform.

The variation of SOC and TN between the 2 years might be due to crop rotation and biomass turnover. Rhizodeposition, root exudates, as well as biomass turnover also varied between the 2 years. In RC treatment, these variations may have caused by the crop rotation. The different significance levels in the 2 years might be due to these variations. The highest contents were observed in GP in 2009 while these were highest in GB in 2010. The lowest contents were observed in the RC treatment in both years. More interestingly, there were significant variations among treatments in 2009 while these were not significantly differences in 2010.

Undoubtedly, there were significant depth effects. There was a greater decline of SOC content in perennial vegetation from surface to sub-surface soil compared to the row crop treatment (Shamir and Steinberger 2007; Tangjang et al. 2009). The mixing associated with conventional tillage in RC might also have contributed towards homogenization of the top 20-cm depth soil. This supports the hypothesis that enzyme activities and water stable aggregates are greater in the surface soil compared to sub-surface soil.

Enzyme activities

Following the dynamics of WSA and organic matter, the study showed significant differences in selected enzyme activities. The β-glucosidase and β-glucosaminidase enzyme activities were most consistent between the 2 years. These activities were significantly higher in perennial vegetation treatments compared to row crop management in both years and these findings agree with results from related research

(Acosta-Martínez et al. 2003; Dick et al. 1996; Kremer and Li 2003; Mungai et al. 2005; Udawatta et al. 2008, 2009; Kremer and Kussman 2011). In a study by Ekenler and Tabatabai (2003), significantly reduced β-glucosaminidase activity has been attributed to soil disturbance and conventional tillage. The higher activities of these enzymes can also be attributed to the increased organic matter and greater activities of roots compared to conventionally cultivated crop areas (Myers et al. 2001; Kremer and Li 2003; Mungai et al. 2005) and the enzyme activities were highly correlated with the soil carbon and nitrogen (Tables 5, 6). Moreover these enzymes have been associated with functional microbial diversity as these are involved in carbon and nitrogen cycling in soil.

Nevertheless the variation of the other two enzymes (FDA and dehydrogenase) was diverse between the 2 years. Variations in precipitation patterns and amounts in the sampling sites during 2 years might also have affected the variation of these indicators over the years. The FDA activities were not significantly different in 2009 among treatments. However, GB treatment showed significantly higher FDA activities compared to the RC treatment in 2010. Dehydrogenase activities were significantly higher in the GP treatment compared to the RC treatment in 2009. Higher activity in GP may be due to slight increase in surface bulk density that seems to stimulate microbial activity (Pengthamkeerati et al. 2011). In 2010, all perennial vegetation treatments revealed significantly higher dehydrogenase activities compared to the row crop treatment. The varied nature of these enzymes could be due to their broad spectrum of activities which represent viable microorganism activities in the soil (Miller et al. 1998; Gaspar et al. 2001; Kandeler 2007). The higher variation of dehydrogenase activities in the 2 years in the RC treatments could be due to crop rotation and time of sampling. Studies show that soil management and cover type influence soil microorganism population, diversity, and soil microbial processes. These in turn cause the changes in the quantity and quality of plant residue, accumulation of biomass, and root carbon in the soil profile and by providing a vigorous environment (Bandick and Dick 1999; Boerner et al. 2000; Doran 1980; Kandeler et al. 1999). Additionally, varying tillage operations, crop rotation, perennial vegetation, residue decomposition and cropping systems influence microbial diversity and enzyme activity due to changes in substrate quantity, soil moisture, and temperature (Doran et al. 1998; Mungai et al. 2005). A similar agroforestry (Mungai et al. 2005) and aforested ecosystem study (Myers et al. 2001) showed that microbial communities and enzyme activities were directly correlated with quality and quantity of vegetation cover. Differences were attributed to quantity and biochemical properties of the organic materials.

The enzyme activities observed in this study support the hypothesis that perennial vegetation provides more favorable conditions for enzyme activity and microbial diversity than row cropping. Collectively, the results from this study and those by Kremer and Li (2003) and Udawatta et al. (2008, 2009) confirm that permanent vegetation leads to carbon accumulation and improvements in selected soil quality indicators compared to row cropping.

Table 5 Correlation coefficients (r) of β-glucosidase, β-glucosaminidase, dehydrogenase and FDA enzyme activities, with soil organic carbon and total nitrogen content (year 2009)

Parameters	β-glucosidase	β-glucosaminidase	Dehydrogenase	FDA
Soil organic carbon	0.94 ($P < 0.0001$)	0.93 ($P = 0.0001$)	0.81 ($P = 0.0001$)	0.78 ($P = 0.0003$)
Total nitrogen	0.93 ($P = 0.0001$)	0.92 ($P = 0.0001$)	0.83 ($P < 0.0001$)	0.78 ($P = 0.0004$)

Table 6 Correlation coefficients (r) of β-glucosidase, β-glucosaminidase, dehydrogenase and FDA enzyme activities, with soil organic carbon and total nitrogen content (year 2010)

Parameters	β-glucosidase	β-glucosaminidase	Dehydrogenase	FDA
Soil organic carbon	0.86 ($P < 0.0001$)	0.88 ($P < 0.0001$)	0.89 ($P < 0.0001$)	0.84 ($P < 0.0001$)
Total nitrogen	0.84 ($P < 0.0001$)	0.84 ($P < 0.0001$)	0.85 ($P < 0.0001$)	0.82 ($P < 0.0001$)

Many of these differences can also be attributed to a greater volume of roots for perennials than row crops. The perennials perpetuate these changes because increased enzyme activities contribute to favorable soil carbon and nitrogen balance, which favors root growth and promotes microbial activity.

Conclusions

The study showed that agroforestry and grass buffers in grazed pasture areas had a significant effect on several soil quality indicators in less than 10 years. The soil quality indicators were consistent during the two measurement years and significantly greater in permanent vegetation areas compared to RC areas. These results show that both organic matter additions from vegetation and soil disturbance through cultivation influence enzyme activities in the soil. Therefore, evaluating and correlating soil enzyme activities with various soil properties can be an effective method for assessing management effects on soil quality.

Soil organic matter changes are relatively slow and thus a long time period is required to detect soil quality effects. Water stable aggregation and enzyme activity changes, however, can be detected in a shorter period of time thus helping to detect and identify effects of management practices more quickly. Assessing changes in selected enzyme activities might be a useful tool to determine land degradation under certain management practices when reference values for similar systems are available. This and other studies in similar areas confirm that establishment of buffers can help to reduce non-point source pollution from agricultural lands. This study also shows that establishment of agroforestry and grass buffers in grazed pasture can enhance soil quality and thus help maintain ecosystem sustainability. These results are also an important contribution to the soil quality literature which is weakest with regard to measured enzyme activity effects and will certainly add to the knowledge base and help improve our understanding of these management systems.

Acknowledgments This work was funded through the University of Missouri Center for Agroforestry under cooperative agreements 58-6227-1-004 with the USDA-ARS. Any opinions, findings, conclusions or recommendations expressed in this publication are those of the authors and do not necessarily reflect the view of the U.S. Department of Agriculture. We would also like to express our thanks to Yarrow Titus, Jim Ortbals and Aquib Choudhry for assisting in the field and laboratory work.

References

Acosta-Martínez V, Zobeck TM, Gill TE, Kennedy AC (2003) Enzyme activities and microbial community structure in semiarid agricultural soils. Biol Fertil Soils 38:216–227

Andrews SS, Karlen DL, Cambardella CA (2004) The soil management assessment framework: a quantitative evaluation using case studies. Soil Sci Soc Am J 68:1945–1962

Angers DA, Mehuys GR (1993) Aggregate stability to water. In: Carter MR (ed) Soil sampling and methods of analysis. Canadian Society of Soil Science, Lewis Publishers, Boca Raton, FL, pp 651–657

Bandick AK, Dick RP (1999) Field management effects on soil enzyme activities. Soil Biol Biochem 31:1471–1479

Beare MH, Cabrera ML, Hendrix PF, Coleman DC (1994) Aggregate-protected and unprotected organic matter pools in conventional- and no-tillage soils. Soil Sci Soc Am J 58:787–795

Bielinska EJ, Pranagal J (2007) Enzymatic activity of soil contaminated with triazine herbicides. Pol J Environ Stud 16:295–300

Bird SB, Herrick JE, Wander MM, Murray L (2007) Multi-scale variability in soil aggregate stability, implications for understanding and predicting semi-arid grassland degradation. Geoderma 140:106–118

Blake GR, Hartge KH (1986) Bulk density. In: Klute A(ed) Methods of soil samples. Part 1, 2nd edn. Agronomy Monograph 9. ASA, Madison, pp 363–375

Boerner REJ, Decker KLM, Sutherland EK (2000) Prescribed burning effects on soil enzyme activity in a southern Ohio hardwood forest: a landscape-scale analysis. Soil Biol Biochem 32:899–908

Burns RG (1983) Extracellular enzyme–substrate interactions in soil. In: Slater JH, Wittenbury R, Wimpenny JWT (eds) Microbes in their natural environment. Cambridge University Press, London, pp 249–298

Cambardella CA, Elliott ET (1992) Particulate soil organic matter changes across a grassland cultivation sequence. Soil Sci Soc Am J 56:777–783

Clement CR, Williams TE (1967) Leys and soil organic matter. II. The accumulation of nitrogen in soils under different leys. J Agric Sci 69:133–138

Denef K, Six J, Merckx R, Paustian K (2002) Short term effects of biological and physical forces on aggregate formation in soils with differing clay mineralogy. Plant Soil 246:185–200

Dick RP (1994) Soil enzyme activities as indicators of soil quality. In: Doran JV, Coleman DC, Bezdicek DF, Stewart BA (eds) Defining soil quality for a sustainable environment. SSSA-ASA, Madison, pp 107–124

Dick RP, Breakwell DP, Turco RF (1996) Soil enzyme activities and biodiversity measurements as integrative microbiological indicators. In: Doran JW, Jones AJ (eds) Methods of assessing soil quality. SSSA special publication 49, Soil Science Society of America Journal, Madison, pp 247–271

Doran JW (1980) Soil microbial and biochemical changes associated with reduced tillage. Soil Sci Soc Am J 44:765–771

Doran JW, Parkin TB (1994) Defining and assessing soil quality. In: Doran JW, Coleman DC, Bedzdicek DF, Stewart BA (eds) Defining soil quality for a sustainable environment. SSSA Special Publication 35, Soil Science Society of America, Inc., and American Society of Agronomy, Inc., Madison, pp 3–21

Doran JW, Elliott EW, Paustian K (1998) Soil microbial activity, nitrogen cycling, and long-term changes in organic carbon pools as related to fallow tillage management. Soil Till Res 49:3–18

Ekenler M, Tabatabai MA (2003) Tillage and residue management effects on β-glucosidaminase activity in soils. Soil Biol Biochem 35:871–874

Elliott LF, Lynch JM (1984) The effect of available carbon and nitrogen in straw on soil and ash aggregation and acetic acid production. Plant Soil 78:335–343

Escobar AG, Kemp PD, Mackay AD, Hodgson J (2002) Soil properties of a widely spaced, planted poplar (*Populus deltoides*)—pasture system in a hill environment. Aust J Soil Res 40:873–876

Franzluebbers AJ, Stuedemann JA (2005) Bermudagrass management in the Southern Piedmont USA. VII. Soil-profile organic carbon and total nitrogen. Soil Sci Am J 69:1455–1462

Franzluebbers AJ, Stuedemann JA, Schomberg HH, Wilkinson SR (2000) Soil C and N pools under long-term pasture management in the Southern Piedmont USA. Soil Biol Biochem 32:469–478

Frey SD, Six J, Elliott ET (2003) Reciprocal transfer of carbon and nitrogen by decomposer fungi at the soil–litter interface. Soil Biol Biochem 35:1001–1004

Gaspar ML, Cabello MN, Pollero R, Aon MA (2001) Fluorescein diacetate hydrolysis as a measure of fungal biomass in soil. Curr Microbiol 42:339–344

Gianfreda L, Rao MA, Piotrowska A, Palumbo G, Colombo C (2005) Soil enzyme activities as affected by anthropogenic alterations: intensive agricultural practices and organic pollution. Sci Total Environ 341:265–279

Gold MA, Garrett HE (2009) Agroforestry nomenclature, concepts and practices. In: Garrett HE (ed) North American agroforestry: an integrated science and practice, 2nd edn. ASA, Madison, pp 45–55

Green VS, Cavigelli MA, Dao TH, Flanagan DC (2005) Soil physical and aggregate-associated C, N, and P distributions in organic and conventional cropping systems. Soil Sci 10:822–831

Guo Z, Yan G, Zhang R, Li F, Zeng Z, Liu H (2010) Improvement of soil physical properties and aggregate-associated C, N, and P after cropland was converted to grassland in semiarid Loess Plateau. Soil Sci 175:99–104

Handayani IP, Coyne MS, Barton C, Workman S (2008) Soil carbon pools and aggregation following land restoration: Bernheim forest, Kentucky. J Environ Restor Monit 4:11–28

Haynes RJ, Williams PH (1993) Nutrient cycling and soil fertility in the grazed pasture ecosystem. Adv Agronom 49:119–199

Ingham E (2000) The Vermicompost foodweb: effects on plant production. Oral Scientific Sessions, The Vermillenium (Conference), Kalamazoo. September 21

Jose S, Gillespie AR, Pallardy SG (2004) Interspecific interactions in temperate agroforestry. Agrofor Syst 61:237–255

Kandeler E (2007) Physiological and biochemical methods for studying soil biota and their function. In: Paul EA (ed) Soil microbiology, ecology, and biochemistry. Elsevier, New York, pp 53–83

Kandeler E, Tscherko D, Spiegel H (1999) Long-term monitoring of microbial biomass, N mineralisation and enzyme activities of a Chernozem under different tillage management. Biol Fertil Soils 28:343–351

Kremer RJ, Kussman RD (2011) Soil quality in a pecan–kura clover alley cropping system in the Midwestern USA. Agrofor Syst 83:213–223

Kremer RJ, Li J (2003) Developing weed-suppressive soils through improved soil quality management. Soil Till Res 72:193–202

Kumar S, Anderson SH, Bricknell LG, Udawatta RP, Gantzer CJ (2008) Soil hydraulic properties influenced by agroforestry and grass buffers for grazed pasture systems. J Soil Water Conserv 63:224–232

Lal R (2002) Soil carbon dynamics in cropland and rangeland. Environ Pollut 116:353–362

Lee KH, Jose S (2003) Soil respiration and microbial biomass in a pecan–cotton alley cropping system in southern USA. Agrofor Syst 58:45–54

Lovell ST, Sullivan WC (2006) Environmental benefits of conservation buffers in the United States: evidence, promise, and open questions. Agric Ecosyst Environ 112:249–260

Miller M, Palojarvi A, Rangger A, Reeslev M, Kjøller A (1998) The use of fluorgenic substrates to measure fungal presence and activity in soil. Appl Environ Microbiol 64:613–617

Mungai WN, Motavalli PP, Kremer RJ, Nelson KA (2005) Spatial variation in soil enzyme activities and microbial functional diversity in temperate alley cropping systems. Biol Fertil Soils 42:129–136

Myers RT, Zak DR, White DC, Peacock A (2001) Landscape-level patterns of microbial community composition and substrate use in upland forest ecosystems. Soil Sci Soc Am J 65:359–367

Nelson DW, Sommers LE (1996) Total carbon, organic carbon, and organic matter. In: Sparks DL (ed) Methods of soil analysis-part 3, chemical methods. Soil Science Society of American Journal, Madison, pp 961–1010

Noble AD, Randall PJ, Sparling G, Anderson LS, Adams M, Khanna PK, Raison RJ, Saffina PG, Xu ZH (1998) How trees affect soils? RIRDL Publ 16:124

NRCS (2001) Agricultural management effects on earthworm populations. Soil Quality—Agronomy Technical Note No. 11. http://soils.usda.gov/sqi

Pankhurst CE, Opjel-keller K, Doube BM, Gupta VVSR (1996) Biodiversity of soil microbial communities in agricultural systems. Biodiversity Conserv 5:202–209

Parham JA, Deng SP (2000) Detection, quantification, and charaterization of β-glucosaminadase activity in soils. Soil Biol Biochem 32:1183–1190

Pengthamkeerati P, Motavalli PP, Kremer RJ (2011) Soil microbial activity and functional diversity changed by compaction, poultry litter and cropping in a claypan soil. Appl Soil Ecol 48:71–80

SAS Institute (2008) Statistical software package SAS version 9.2. NC, USA

Schloter M, Dilly O, Munch JC (2003) Indicators for evaluating soil quality. Agric Ecosyst Environ 98:255–262

Schultz RC, Isenhart TM, Simpkins WW, Colletti JP (2004) Riparian forest buffers in agroecosystems—lessons learned from the Bear Creek Watershed, Central Iowa, USA. Agrofor Syst 61:35–50

Shamir I, Steinberger Y (2007) Vertical distribution and activity of soil microbial population in a sandy desert ecosystem. Microb Ecol 53:340–347

Sigua GC (2003) Soils and environment of grazed pasture ecosystems in subtropical United States: trends and research results. J Soil Sediment 3:258–260

Sinsabaugh RL, Antibus RK, Linkins AE (1991) An enzymic approach to the analysis of microbial activity during plant litter decomposition. Agric Ecosyst Environ 34:43–54

Six J, Elliott ET, Paustian K (2000) Soil macroaggregate turnover and microaggregate formation: a mechanism for C sequestration under no-tillage agriculture. Soil Biol Biochem 32:2099–2103

Stott DE, Andrews SS, Liebig MA, Wienhold BJ, Karlen DL (2010) Evaluation of β-glucosidase activity as a soil quality indicator for the Soil Management Assessment Framework. SSSA J 74:107–119

Tabatabai MA (1994) Soil enzymes. In: Weaver RW, Angle JS, Bottomley PS (eds) Methods of soil analysis, microbiological and biochemical properties. SSSA Book. Soil Science Society of America, Madison, pp 775–833

Tangjang S, Arunachalam K, Arunachalam A, Shukla AK (2009) Microbial population dynamics of soil under traditional agroforestry systems in Northeast India. Res J Soil Biol 1:1–7

Tisdall JM, Oades JM (1980) The management of rye-grass to stabilize aggregates of a red-brown earth. Aust J Soil Res 18:415–422

Tisdall JM, Oades JM (1982) Organic matter and water stable aggregates in soils. J Soil Sci 33:141–163

Trasar-Cepeda C, Leiros MC, Seoane S, Gil-Sotres F (2000) Limitations of soil enzymes as indicators of soil pollution. Soil Biol Biochem 32:1867–1875

Udawatta RP, Krstansky JJ, Henderson GS, Garrett HE (2002) Agroforestry practices, runoff, and nutrient loss: a paired watershed comparison. J Environ Qual 31:1214–1225

Udawatta RP, Kremer RJ, Adamson BW, Anderson SH (2008) Variations in soil aggregate stability and enzyme activities in a temperate agroforestry practice. Appl Soil Ecol 39:153–160

Udawatta RP, Kremer RJ, Garrett HE, Anderson SH (2009) Soil enzyme activities and physical properties in a watershed managed under agroforestry and row-crop system. Agric Ecosyst Environ 131:98–104

van Veen JA, Paul EA (1981) Organic carbon dynamics in grassland soils. I. Background information and computer simulation. Can J Soil Sci 61:185–201

Verhoef HA, Brussaard L (1990) Decomposition and nitrogen mineralization in natural and agroecosystems: the contribution of soil animals. Biogeochemistry 11:175–211

Watt M, Kirkegaard JA, Passioura JB (2006) Rhizosphere biology and crop productivity: a review. Aust J Soil Res 44:299–317

Weil RR, Magdoff F (2004) Significance of soil organic matter to soil quality and health. In: Magdoff F, Weil RR (eds) Soil organic matter in sustainable agriculture. CRC Press, Boca Raton, pp 1–45

Young A (1989) Agroforestry for soil conservation. CAB International, Oxford, p 276