Impact of Different Land Use Management on Soil Enzyme Activities in Missouri River Floodplains

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Abstract

Land management activities that provide higher soil organic carbon stimulate microbial activity and enzymatic reactions. Riparian forest, agroforestry, and row-crop agriculture treatments are among common land-use systems in the lower Missouri River Floodplain (MRF) region in New Franklin, MO. The study of soil enzyme activities under different land use in this region is of importance for monitoring soil quality and evaluation of climatic changes on soil health. This investigation aimed to characterize soil properties such as soil C and N, porosity, moisture content under three-land use (agroforestry, riparian forest, and agriculture) and correlate their influence on soil microbial communities and enzyme activities. Soil samples were collected from the three land management systems, and enzyme activity was measured in three seasons of Fall 2019, Summer 2020, and Spring 2021. Results revealed significantly higher levels of β-glucosidase, β-glucosaminidase, and dehydrogenase activity in agroforestry (AF) and riparian forest (RF) treatments relative to agriculture (AG) management in all three studied seasons. Dehydrogenase activity was higher ($p<0.0001$) in RF relative to AF and AG sites. Efforts to incorporate perennial management systems in river-floodplain landscapes will help increase organic matter content, which stimulates microbial diversity and soil enzyme activity as well as improving the performance of conservation buffers. The study concluded that tree-based AF systems enhance soil physicochemical and biological properties.

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Impact of Different Land Use Management on Soil Enzyme Activities in Missouri River Floodplains

Core ideas

- Tree-based agroforestry systems enhance soil physicochemical and microbial properties.
- Agroforestry and forest systems show greater soil enzyme activity relative to row crop agriculture.
- There is a positive correlation between soil enzyme activity, soil porosity, and organic matter content.

ABSTRACT

Land management activities that provide higher soil organic carbon stimulate microbial activity and enzymatic reactions. Riparian forest, agroforestry, and row-crop agriculture treatments are among common land-use systems in the lower Missouri River Floodplain (MRF) region in New Franklin, MO. The study of soil enzyme activities under different land use in this region is of importance for monitoring soil quality and evaluation of climatic changes on soil health. This investigation aimed to characterize soil properties such as soil C and N, porosity, moisture content under three-land use (agroforestry, riparian forest, and agriculture) and correlate their influence on soil microbial communities and enzyme activities. Soil samples were collected from the three land management systems, and enzyme activity was measured in three seasons of Fall 2019, Summer 2020, and Spring 2021. Results revealed significantly higher levels of β-glucosidase, β-glucosaminidase, and dehydrogenase activity in agroforestry (AF) and riparian forest (RF) treatments relative to agriculture (AG) management in all three studied seasons. Dehydrogenase activity was higher ($p<0.0001$) in RF relative to AF and AG sites. Efforts to incorporate perennial management systems in river-floodplain landscapes will help increase organic matter content, which stimulates microbial diversity and soil enzyme activity as well as improving the performance of conservation buffers. The study concluded that tree-based AF systems enhance soil physicochemical and biological properties.

Key words: Soil organic matter, Soil water-filled pore space, β-glucosidase, β-glucosaminidase, Dihydrogenase, Soil microbial activity

Abbreviations: AC, active carbon; AF, agroforestry; AG, row-crop agriculture; C, carbon; CEC, cation exchange capacity; Db, bulk density; f, porosity; HARC, Horticulture and Agroforestry Research Center; MRF, Missouri River Floodplain; N, nitrogen; NA, neutralizable acidity; RF, riparian forest; SOC, soil organic carbon; SOM, soil organic matter; WFPS, water-filled pore space.

1. INTRODUCTION

Enzymes as the main actors of the soil ecosystem are mediating nutrient transformation within the soil. Metabolizing of broad classes of plant tissues (e.g., carbohydrates, phenol structures, and proteins) is carried out by the soil microbial community through enzymatic reactions. Due to their central role in nutrient recycling and transformation, as well as sensitivity to changes in management systems, soil enzymes are suggested to be used as an indicator of soil quality (Dixon & Tilston, 2010; Kremer & Li, 2003). Soil enzymes activities are sensitive to the changes in soil physical properties , soil nutrient availability, and fertility (Eivazi et al., 2003; Verchot & Borelli, 2005; Yuan et al., 2006).

Beta-glucosidase as a predominant soil enzyme mediates biochemical reactions involving soil organic carbon decomposition. The activity of β-glucosidase plays a major role in soil C cycling (Sotomayor-Ramirez et al., 2009). This enzyme catalizes the degradation of cellulose as the main component of plant tissues (Veum et al., 2014), and the hydrolysis products, which include simple sugars, are consumed by soil microorganisms as energy sources (Acosta-Martinez et al., 2000; Eivazi & Tabatabai, 1988; Yuan et al., 2006). It has been known that the activity of β-glucosidase reflects land management (Vallejo et al., 2010).

Both C and N cycling in the soil is controlled by β-glucosaminidase, which involves the decomposition of chitobiose, proteins, lignin, and lignified organic matter releasing N and C (Parham & Deng, 2000). Chitin degradation by β-glucosaminidase provides N mineralizable sources in soil and enhance soil N availability (Sotomayor-Ramirez et al., 2009). Moreover, amino sugars as the hydrolysis products of chitin degradation are the major sources of readily mineralizable C (Acost-Martinez et al., 2007). Beta-glucosaminidase is an important component of fungal cell walls and the activity of this enzyme can be correlated to soil fungi biomass (Parham & Deng, 2000; Yuan et al., 2006).

Dehydrogenase is an intracellular enzyme considered as an indicator of microbial oxidative activity as well as soil fertility. Microbial oxidative activity can be determined by measuring dehydrogenase activity (Jarvan et al, 2014; Kumar et al., 2013; Liang et al. 2014; Veum et al., 2014). Since dehydrogenase is an intracellular enzyme and cannot function outside the living microbial cells (Ekenler, 2002), the activity of this enzyme is viewed as the soil microbial density and respiratory function. However, measuring only dehydrogenase activity is not always a reliable predictor of the total microbial activity in a complex environment such as soil (Salazar et al., 2011).

Although enough oxygen accelerates the microbial decomposition process, oxygen shortage in anaerobic soils lowers the speed of the process by affecting microbial and enzyme activity (Neira et al., 2015). In saturated soils, anaerobes become dominant and respire through some enzymatic reduction processes (Oertel et al., 2016; Ussiri et al., 2009). The hydrology of floodplains and poorly drained soils often results in anaerobic conditions, which influence the prevalence of differing soil microbial consortiums (Frenzel et al., 1992). Soil water content is considered an important factor that controls soil microbial and enzyme activity (Dutaur et al., 2007; Gao et al., 2014; Nag et al., 2017) through changes in oxygen diffusion and nutrient transformation within the soil profile (Gonzalez Mace et al., 2016; Hulicova et al., 2018; Vanhala, 2002). Soil nutrient availability and soil pH are factors that affect soil microbial respiration and enzyme activity (Chapuis-Lardy et al., 2007; Ludwig et al., 2001).

Sustainable agriculture practices to enhance soil productivity are a considerable challenge for modern agriculture (McLaughlin & Kinzelbach, 2015). Conservation activities reduce soil degradation and enhance soil quality by improving soil organic matter (SOM) content (Fabrizzi et al., 2005; Weerasekara et al., 2016). Land management practices affect soil physicochemical and biological properties through changes in soil organic carbon (SOC) (Bordoloi et al., 2016; Merino et al., 2004; Wang et al., 2019). Intensive tillage practices in conventional cropping systems reduce SOC, which is positively correlated to the soil active C (Culman et al., 2012; Sauer et al., 2007; Weil et al., 2003). In contrast, land management activities such as tree-based agroforestry systems (e.g., grass buffer, alley-cropping, shelterbelt) sequester large amounts of C, while also improving soil aggregate stability, water holding capacity, and nutrient retention that stimulates microbial activity and enzymatic reactions (Amadi et al., 2016; Moore et al., 2018; Palma et al., 2007; Veum et al., 2011).

Soil fertilization, cropping strategies, and tillage practices are among land treatments that affect the activity of enzymes (Dick 1984; Tate & Terry, 1980; Weitao et al., 2018). Stott et al.

(2009) applied β-glucosidase activity as a reflector of soil management practices in the Soil Management Assessment Framework (SMAF) equation. Ekenler and Tabatabai (2002) stated that activity of β-glucosaminidase is higher in the fields under crop rotation (corn-oats-meadow) than continuous soybean cultivation. Their findings revealed that N fertilization is in favor of β-glucosaminidase activity. Soil organic and inorganic input as well as perennial vegetation management contribute to dehydrogenase activity (Alagele et al., 2019; Kremer & Li, 2003).

This study was conducted on three selected land management systems: agroforestry, riparian forest, and row-crop agriculture located in the Missouri River Floodplains (MRF). The aim of this study was to characterize soil baseline properties to determine the effects of three selected land management systems on soil key indicators that are known to influence soil enzyme activities. The effect of land management on soil organic matter, moisture content, porosity, and soil microbial activity was investigated.

2. MATERIALS AND METHODS

2.1. Study site

The experiment was conducted in the Horticulture and Agroforestry Research Center (HARC), a primary research site for agroforestry at the University of Missouri, Columbia. This research station sits on the Missouri River Hills (Northern edge) and Missouri River Flood Plains (Southern portion) bordering Sulfur Creek on the South and West sides (Moore et al., 2018). The center is located in New Franklin, MO (39º 0´ 50˝ N, 92° 44´ 55˝ W). Three selected land management systems under investigation in this study were row crop agriculture {corn [*Zea mays* L.]/soybean [*Glycine max* (L.) Merr.]} (AG), agroforestry [pecan (*Carya illinoinensis*) orchard/hay (AF), and a riparian forest area (RF) along Sulphur Creek. Soils consist of Ap and C horizons formed in alluvium, which are Nodaway silt loam and categorized as Fine-silty, mixed, superactive, nonacid, mesic Mollic Udifluvents. Mean annual precipitation and temperature are 1070 mm and 12.6 °C, respectively (Moore et al., 2018).

The AF treatment includes a combination of four groups of thirty-two pecan trees (28 years of age and 14 m distance), grasses of tall fescue (*Festuca arundinacea*), and Johnson grass (*Sorghum halepense*). The AF treatment received nitrogen-based fertilizer in 2020 (~110 kg ha^{-1}), and March 2021 (~70 kg ha^{-1}) in the form of urea. In 2019, due to severe flooding events, no fertilizer was added to the site. No hay has been removed from the agroforestry site for at least the past 6 years. From 2016 to 2022, the grass has been cut 2-3 times per season and left on the soil surface. The RF is an area along Sulphur Creek covered by silver maple (*Acer saccharinum*), American elm (*Ulmus americana*), sycamore (*Platanus occidentalis*), and cottonwood (*Populus deltoides*). It does not receive any direct fertilizer; however, due to regular flash floods, it receives some sediment, and run-off from whatever washes down the stream next to it (Sulphur Creek). The AG field is a corn-soybean rotation system in which corn was planted in 2018, and soybean was cultivated in May 2019 and 2020. No N fertilizer was applied in the soybean and corn year (2021) of the rotation.

2.2. Soil sampling

In the AF treatment, soil samples were collected and composited (0-15 cm) about 2 m from pecan trees to investigate the effect of tree-grass root systems on the soil physicochemical properties and enzyme activity. In the RF, soil samples were taken 2 m from trees to evaluate the effect of trees as well as underbrush root systems on soil properties. In the AG treatment, soils were taken from 6 m intervals within the soybean rows and between rows. Six replicates at each site were collected at each sampling event in 2019 and 2020. In 2021, three composited subsamples of six replicates at each site were collected. Soil samples in sealed plastic bags were placed in a cooler and transported to the laboratory. The samples were stored at 4 °C until analysis was conducted.

2.3. Soil physical and chemical properties

Soil bulk density (Db) was measured using the core method described by Topp and Ferre (2002). In total, 18 soil samples were collected (six from each treatment) from three selected treatments using the soil core (Uhland) sampler (7.6 cm diam. by 7.6 cm long). Soil cores were covered by plastic caps at the top and bottom, then placed in sealed plastic bags and carried in a cooler to the laboratory. Having the core volume, soil bulk density was obtained from the differences between moist and oven-dried (105 °C) soil cores. Soil moisture content was measured using the gravimetric water content method explained by Topp and Ferre (2002) (Fig. 1). This method is based on the weight differences between moist and oven-dried soil (105 °C). Soil porosity (f) was calculated using the bulk density and soil particle density (ρs) of 2.65 g cm^{-3} ($f = 1 - Db/\rho s$). Due to severe weather conditions and frequent flooding events, soil moisture was not measured in 2019. However, to simulate the effect of each treatment on the soil moisture, weekly measurements were carried out in Spring, Summer, and Fall 2020 and 2021 (May-October).

Using standard soil testing procedures, soil samples were analyzed by the University of Missouri Soil and Plant Testing Laboratory for particle size distribution, soil pH, SOM, neutralizable acidity (NA), cation exchange capacity (CEC), Bray 1-P, calcium, magnesium, and potassium content (Nathan et al., 2012). Soil mineralizable N and active carbon were evaluated by the University of Missouri Soil Health Assessment Center (Anderson et al., 2010; NRCS, 2004). Composite soil samples from AF, RF, and AG treatments were collected as explained before and sent to the assessment center for the tests.

2.4. Soil microbial community characterization

A phospholipid fatty acid (PLFA) test was carried out by the University of Missouri Soil Health Assessment Center (SHAC) using the protocol developed by Buyer and Sasser (2019). Mycorrhizal fungi, gram-negative, gram-positive bacteria, and actinobacteria biomass were evaluated for the three land management systems (AF, RF, and AG) in Spring 2021 (May). The row-crop agriculture field was in the corn phase of the rotation this year.

2.5. Soil enzyme activity assays

Soil samples were collected (0-15 cm) from AF, RF, and AG management systems using a soil auger probe in Fall 2019 (mid-October and early November), Summer 2020 (late July and early September), and Spring 2021 (late May). Soils were air-dried, grounded, and sieved for less than 2 mm. The activity of β-glucosidase and β-glucosaminidase was investigated for Fall 2019, Summer 2020, and Spring 2021. The activity of dehydrogenase was measured for Summer 2020, and Spring 2021.

β-glucosidase activity was determined according to the procedure developed by Eivazi and Tabatabai (1988). The method is based on the colorimetric determination of *p*-nitrophenol (PNP) released by the substrate (*p*-nitrophenyl-β-D-glucoside) with 1-g sieved air-dried soil samples incubated with buffered (pH 6.0) *p*-nitrophenol-β-D-glucoside. The soil was incubated with the p-nitrophenyl-β-D-glucoside substrate for one our at pH 6.0 at 37 °C.

β-glucosaminidase activity was measured according to the protocol developed by Parham and Deng (2000). 1-g sieved air-dried soil samples incubated for one hour with *p*-Nitrophenyl-N-acetyl-β-D-glucosaminide buffered (pH 5.5). Redeveloped calibration equations were used to calculate the concentration of *p*-nitrophenol calorimetrically (410 nm), and the activity of both enzymes was expressed in l g *p*-nitrophenol g^{-1} dry soil.

Dehydrogenase activity (DHA) was determined based on the reduction of 2, 3, 5-Triphenyltetrazolium chloride (TTC) to the Triphenyl formazan (TPF) as described by Tabatabai (1994). Triphenyltetrazolium chloride was added to 20 g of air-dried soil (<2mm) and incubated (37 °C) for 24 hours. The concentration of red-colored TPF was measured with a spectrophotometer unit (Genesys 10 µv Spectrophotometer) set at 485 nm. The activity of dehydrogenase was expressed in l g TPF g^{-1} dry soil.

2.6. Statistical analysis

Significant differences were obtained applying the general linear model (GLM) procedure (One-Way ANOVA) according to the least significant difference (LSD) at $p<0.05$ for the enzyme activity in three land management systems for each season and year separately. The Statistical Analysis System, SAS studio (OnDemand for Academics edition) was applied. Pearson correlation analysis was performed to evaluate the relationship between physical and biological soil properties. Soil properties data from Fall 2019 was used to investigate the association between variables.

3. RESULTS AND DISCUSSION

3.1. Soil physicochemical properties

Soil organic matter content was significantly greater in AF (2.7%) and RF (2.5%) as compared to AG (Table 1). Tree roots extension, nitrogen fixation, fungi biomass, crown expansion, and litterfall in tree-based systems contribute to the nutrient cycling and OM build-up (A Bear et al., 2014; Mishra et al., 2003). Also, active C and mineralizable N were the lowest in AG management as compared to RF and AF (Table 1). Biomass removal from agricultural fields (grain harvesting and straw removal practices) reduce the potential of soil C sequestration in these systems (Baah-Acheamfour et al., 2014; Paustian et al., 2000). Forest and tree-based agroforestry systems are considered large sinks of soil C due to annual litterfall, fine root exudation, and decomposition compared to many row-crop agricultural systems (Baah-Acheamfour et al., 2014; Montagnini & Nair, 2004). Fertilizer application and plant litter N content could increase soil mineralizable N concentration in the AF management relative to RF and AG (Franzluebbers et al., 2017; Palm et al., 2002). The larger active C and mineralizable N content in the AF and RF could be attributed to the greater soil microbial biomass of these systems relative to AG (Fig. 3). Moreover, decayed soil microbial biomass releases C and N into the soil increasing SOC and mineralizable N (Veum et al., 2018).

Soil bulk density in the AG management was higher (1.29g/cm^3) compared to AF (1.19 g/cm^3) and RF (1.14 g/cm^3) treatments (Table 1). More organic matter quantity and quality in the AF and RF systems contribute to better soil porosity and lower bulk density in both systems. Tillage and soil disturbance in row crop systems affect the bulk density negatively due to the soil compaction (Jiang et al., 2007; Moore et al., 2018; Udawatta and Anderson, 2008), while grass establishment and lower soil disturbance promote the lower soil bulk density (Alagele et al., 2019; Seobi et al., 2009).

Soil porosity (f) was significantly higher ($p < 0.0001$) in AF and RF rather than in the AG management system (Table 1). Land-use systems including tree roots such as agroforestry and riparian forest systems promote soil porosity (Rachman et al., 2005). Significantly larger organic matter content and abundance of roots and biopores in AF and RF systems lower the D_b and increase soil porosity (Mishra et al., 2003; Udawatta & Anderson, 2008).

Soil pH in RF (6.1) system was significantly greater relative to AF (5.3) and AG (5.7) with no significant difference between AF and AG (soybean phase) (Table 1). Lower mean soil pH in AF is attributed to the fertilizer application and nutrient acquisition by microorganisms and root systems (including extensive grass root system) in surface layers (Divito et al., 2011; Fujii, 2014; Mishra et al., 2003).

TABLE 1 Selected soil properties (0-15cm) of three land management systems in the Missouri River Floodplain (MRF) at Horticulture and Agroforestry Research Center (HARC), New Franklin, MO. Data followed by the same uppercase letter within each column did not differ significantly at P<0.05.

Site	Bulk density	Porosity	Organic matter	NA[1]	CEC[2]	pH_w	Active C	Min. N[3]	Bray 1 P	Ca	Mg	K
	$g\ cm^{-3}$	%		$cmolc\ kg^{-1}$			$mg\ kg^{-1}$		$kg\ ha^{-1}$			
Agroforestry (AF)	1.19 (0.02)^{a}	54 (1.2)^{a}	2.7 (0.13)^{a}	4.0 (0.7)^{a}	15.2 (0.8)^{a}	5.4 (0.15)^{a}	400	100	51 (4.0)^{a}	3225 (238)^{a}	446 (30)^{ab}	289 (17)^{a}
Riparian forest (RF)	1.14 (0.02)^{b}	58 (0.9)^{b}	2.5 (0.09)^{a}	1.0 (0.24)^{b}	11.4 (0.5)^{b}	6.1 (0.09)^{b}	597	92	69 (4.0)^{a}	3209 (254)^{a}	399 (25)^{a}	216 (11)^{b}
Row-crop agriculture (AG)	1.29 (0.04)^{c}	49 (1.1)^{c}	1.7 (0.04)^{b}	1.9 (0.17)^{b}	13.4 (0.8)^{ab}	5.7 (0.06)^{a}	353	46	70 (13)^{a}	4322 (217)^{b}	533 (22)^{b}	324 (19)^{a}

[1] neutralizable acidity
[2] cation exchange capacity
[3] mineralizable N

Soil water-filled pore space was higher in the AF system in all three seasons for two years (Fig. 1). Due to flooding events, in summer 2020 and spring/summer 2021 AF showed significantly higher (p<0.0001) soil WFPS% as compared to RF and AG. The average soil WFPS% in Summer 2020 was 80, 64, and 54 for AF, RF, and AG land management systems, respectively. In Spring 2021, mean WFPS% was 67, 58, and 53 for AF, RF, and AG respectively. Baah-Acheamfour et al. (2014) observed higher water holding capacity in forest and agroforestry systems than in row-crop agriculture. Improved soil properties (e.g., porosity, SOM) in agroforestry and forest systems enhance soil water holding capacity and soil WFPS in these management systems relative to row-crop agriculture (Baily et al., 2009; Udawatta et al., 2006). Baah-Acheamfour et al. (2016) observed lower soil water content in forestland covers than their herbland counterparts across agroforestry systems. Baily et al. (2009) observed a range of WFPS between 60-80% in agroforestry (grass-tree) systems in Spring. Although soil porosity is greater in the RF, lower WFPS in this system relative to AF could be associated with the "safety-net hypothesis" through which extensive tree roots take up water and reduce soil WFPS (Evers et al., 2010). Water-filled pore space is a limiting factor to microbial movement within the soil profile. In addition, soil moisture content influences soil fungi biomass and enzyme activity (Borowik et al., 2016).

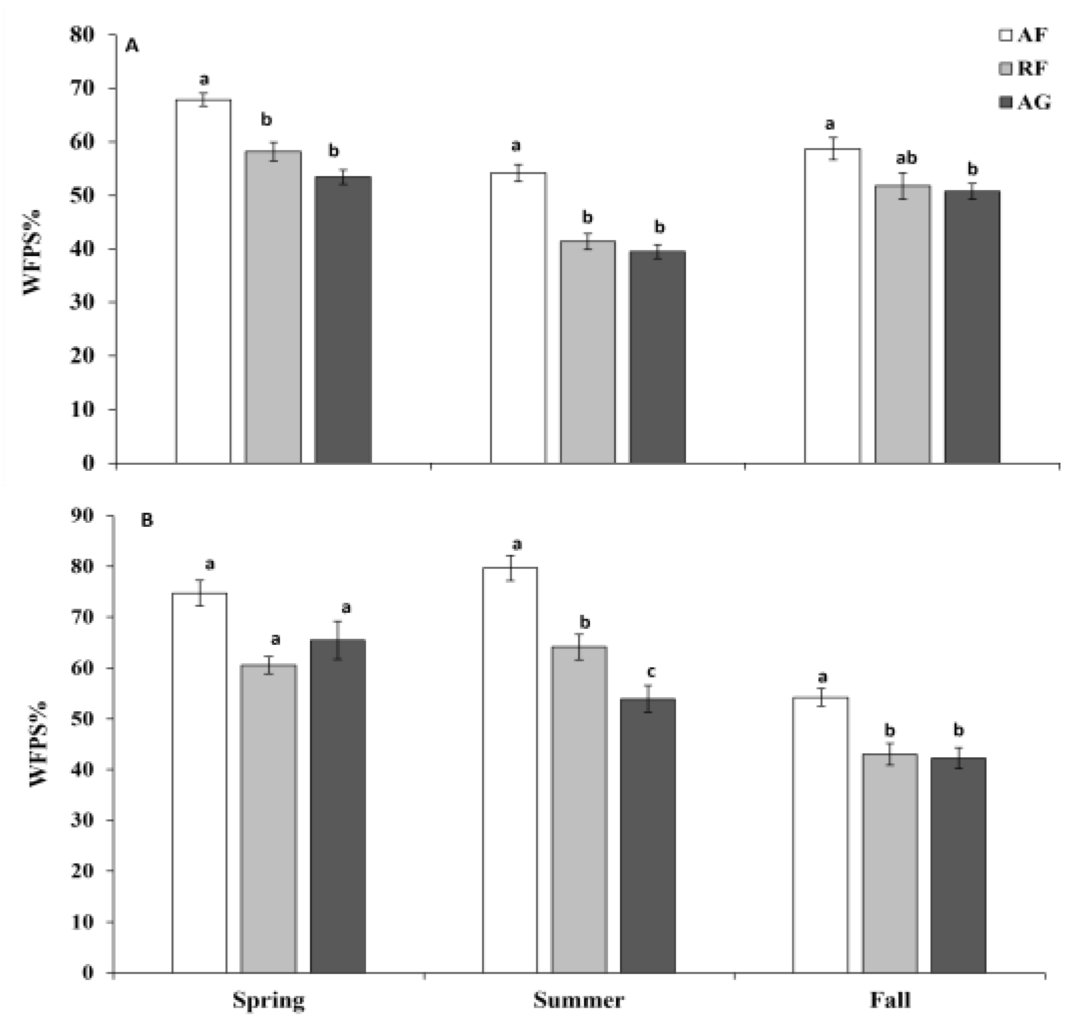

FIGURE 1 Water-filled pore space measured seasonally in two years 2021, A); and 2020, B) for three selected land management systems: agroforestry (AF), riparian forest (RF), and agriculture (AG) in the Missouri River Floodplains (MRF).

3.2. Soil microbial activity

The greatest mycorrhizal fungi and total fungal biomass were observed in the RF management followed by AF and AG, respectively (Fig. 3). Accumulation of organic matter from tree roots and vegetation stimulated fungi activity, decomposition of complex organic matter components of lignin, pectins, and cellulose enhancing total PLFA while tillage and row-crop production reduce SOM content and fungal community (Barber et al., 2017; Kremer & Veum, 2015, 2020). Gram-negative, gram-positive, and actinobacteria are highest in RF followed by AF and AG systems. This could be attributed to the greater decomposition rate of organic matter by fungi (greater in both RF and AF) into simpler components that support the bacterial community (Kremer & Veum, 2015).

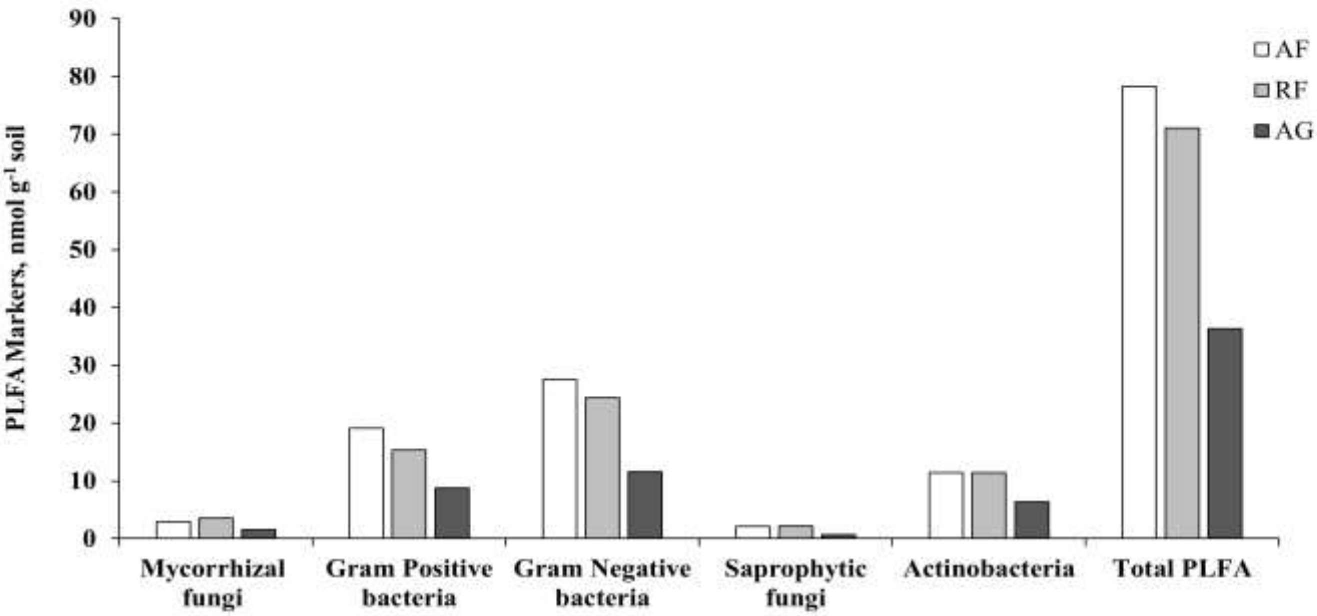

FIGURE 2 PLFA soil microbial community (nmol/g soil) for three land management systems: agroforestry (AF), riparian forest (RF), and agriculture (AG) in the Missouri River Floodplain (MRF) at Horticulture and Agroforestry Research Center (HARC), New Franklin, MO.

3.3. Soil enzyme activity

Results from Fall 2019 revealed that the activity of β-glucosidase was significantly greater in AF ($p < .0001$) and RF ($p < .006$) management relative to AG (Fig. 4). The highest mean β-glucosidase activity (116 µg *p*NP g^{-1} soil h^{-1}) was observed in the AF treatment, while the lowest activity (77 µg *p*NP g^{-1} soil h^{-1}) was attributed to the AG. In Summer 2020, the activity of β-glucosidase was substantially greater in RF ($p<0.0001$) and AF ($p=0.007$) treatments (100 µg *p*NP g^{-1} soil h^{-1} and 77 µg *p*NP g^{-1} soil h^{-1} respectively) as compared to AG (46 µg *p*NP g^{-1} soil h^{-1}). B-glucosidase activity reached the highest ($p<0.0001$) in Spring 2021 in RF (205 µg *p*NP g^{-1} soil h^{-1}) compared with AF and AG. The mean activity of β-glucosidase in AF (153 µg *p*NP g^{-1} soil h^{-1}) was significantly higher than the AG system (99 µg *p*NP g^{-1} soil h^{-1}).

The average activity of β-glucosaminidase in the AF and RF systems (41 and 40 µg *p*NP g^{-1} soil h^{-1} respectively) was significantly higher ($p<0.0001$) in comparison with the AG management system (24 µg *p*NP g^{-1} soil h^{-1}) in Fall 2019. The results from Summer 2020 revealed that the greatest β-glucosaminidase activity occurred in the RF system (Fig. 4). The activity of β-glucosaminidase in AG (21 µg *p*NP g^{-1} soil h^{-1}) was lower compared to AF (41 µg *p*NP g^{-1} soil h^{-1}; $p<0.0004$) and RF (36 µg *p*NP g^{-1} soil h^{-}1; $p<0.006$) management systems. In Spring 2021, the greatest activity of β-glucosaminidase ($p<0.0001$) was observed in RF and AF systems (76 and 67 µg *p*NP g^{-1} soil h^{-1} respectively) as compared to AG (19 µg *p*NP g^{-1} soil h^{-1}).

Dehydrogenase activity was significantly higher in the RF system both in Summer 2020 (0.4 µg TPF g^{-1} soil h^{-1}) and Spring 2021 (0.5 µg TPF g^{-1} soil h^{-1}) followed by AF (0.2 µg TPF g^{-1} soil h^{-1}). The lowest dehydrogenase activity was observed in the AG land management. The mean value of dehydrogenase activity was 0.09 µg TPF g^{-1} soil h^{-1} in Summer 2020. The lowest dehydrogenase activity was observed in Spring 2021 (0.07 µg TPF g^{-1} soil h^{-1}) (Fig. 4).

Several studies have shown greater enzyme activity in tree-based and perennial vegetation systems relative to row crop agriculture (Acosta-Martinez et al., 2007; Kremer & Li 2003; Kumar et al., 2013; Pascual et al., 2000; Paudel et al., 2012; Udawatta et al., 2008, 2009; Weerasekara et al., 2016). In an agroforestry (tree/grass) system, Alagele et al. (2019) found mean activities of 160 and 90 µg *p*NP g $^{-1}$ soil h $^{-1}$ for the β-glucosidase and β-glucosaminidase respectively. The authors found lower activity in a row crop (corn/soybean) system (β-glucosidase: 118 µg *p*NP g $^{-1}$ soil h $^{-1}$; β-glucosaminidase: 70 µg *p*NP g $^{-1}$ soil h $^{-1}$) relative to agroforestry (Fig. 4) (Alagele et al., 2019). Bonanomi et al. (2011) found a lower dehydrogenase activity (0.89 µg TPF g $^{-1}$ soil h $^{-1}$) in farms under intensive cultivation management relative to the tree orchard system (5.41µg TPF g $^{-1}$ soil h $^{-1}$). Our results for dehydrogenase activity (Fig. 4) in the corn/soybean system are similar to those reported by Xavier et al. (2019) (0.05 and 0.06 µg TPF g^{-1} soil h^{-1} for corn and soybean monoculture respectively).

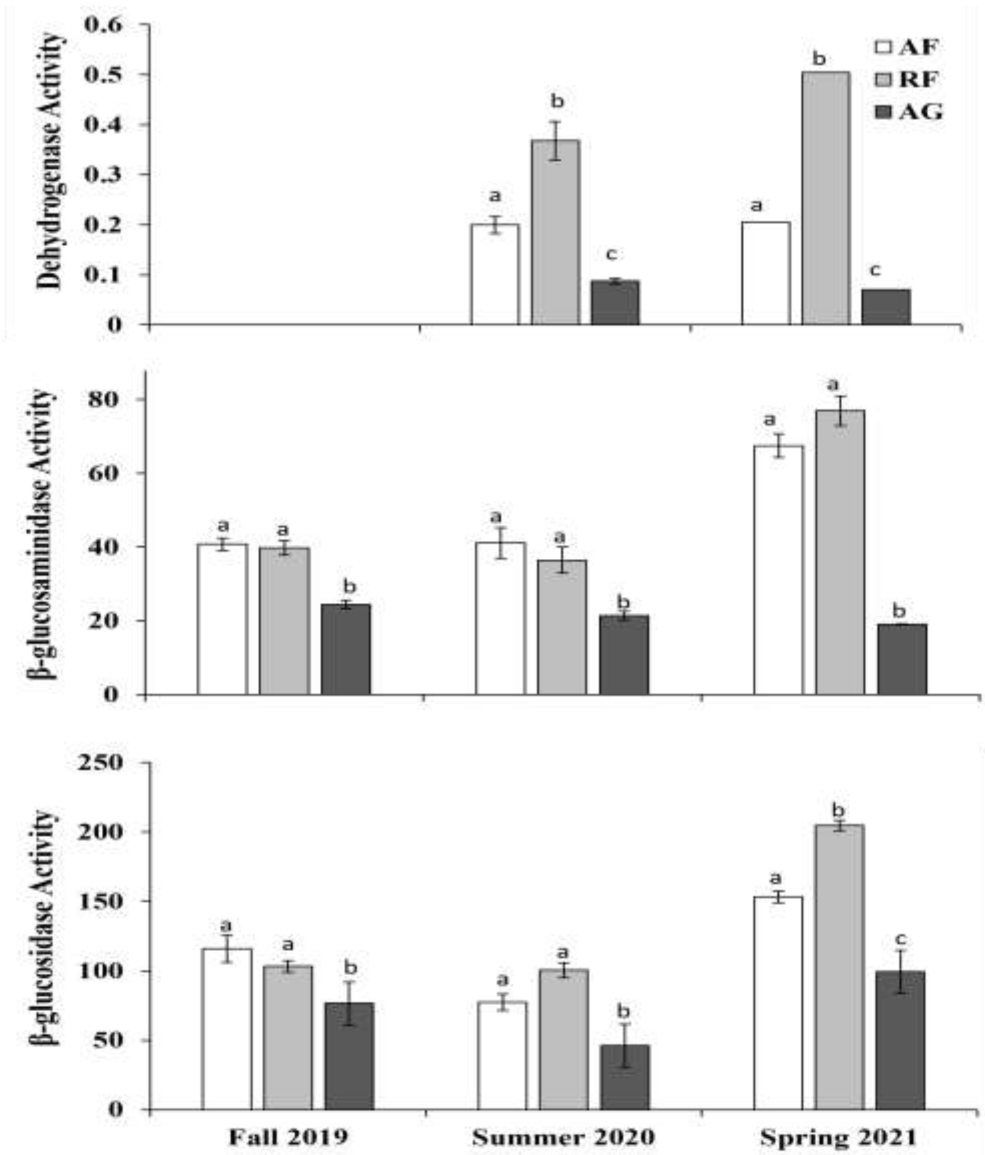

FIGURE 3 The activity of β-glucosidase, β-glucosaminidase (μg *p*NP g $^{-1}$ soil h $^{-1}$), and dehydrogenase (μg TPF g $^{-1}$ soil h $^{-}$1) for three land management systems in the Missouri River Floodplain (MRF) at Horticulture and Agroforestry Research Center (HARC), New Franklin, MO. Different lowercase letters indicate statistically significant differences (LSD<0.05).

Variability of enzyme activity within the treatments were almost always greater in RF and AF land management systems relative to row-crop AG (Fig. 4). These variations could be attributed to the greater soil heterogeneity in the AF and RF systems due to the several vegetation covers and root systems compared to the AG field. Wallenius et al. (2011) found a higher soil enzyme variability in forest topsoil as compared to soils of meadow and organic farming fields. Increased enzyme activity in the RF and AF systems relative to AG in all sampling times could be attributed to the improved soil properties (SOM%, porosity, microbial biomass, and WFPS%).

Results from the correlation analysis in 2019 showed that β-glucosidase and β-glucosaminidase were significantly correlated with the SOM% (Table 2). It has been noted in the literature that there is a positive relationship between soil enzyme activity and soil organic matter and SOC (Acosta-Martinez et al., 2007; Kremer & Hezel, 2013; Moreno et al., 2021). Larger microbial communities in agroforestry and forest systems due to high input and diversity of organic material increase enzyme activity relative to conventional monoculture systems (Asuming-Brempong et al. 2008; Vallejo et al., 2010). Kremer and Hezel (2013) stated that no-tillage practices and vegetative residues enhance dehydrogenase and β-glucosidase activity by 60-73% in the fields with native plants relative to croplands under conventional tillage practices.

Moreover, improved soil porosity in the AF and RF contributed to higher enzyme activity in these treatments as compared to AG. This study found a strong correlation between β-glucosidase and β-glucosaminidase activity and soil porosity (Table 2). Findings from several studies showed that greater bulk density (due to heavy traffic) and lower porosity in monoculture systems relative to agroforestry and forest land management negatively affect microbial biomass and enzyme activity (Ekenler &Tabatabai, 2003; Klose & Tabatabai, 1999; Udawatta et al., 2009; Vallejo et al., 2010).

TABLE 2 Relationship between some soil physicochemical and biological properties. To evaluate the correlation, data from three land management systems of agroforestry, row crop agriculture, and the riparian forest was used. Values are Pearson correlation coefficients and p values (in parentheses).

Enzyme activity	Organic matter	Porosity
β-glucosidase	0.69 (0.001)	0.47 (0.04)
β-glucosaminidase	0.82 (<0.0001)	0.43 (0.07)

β-glucosaminidase activity in the AF management might have been affected by N fertilizer application at the beginning of the growing season because fertilizer application induces the activity of this enzyme (Alster et al., 2013; Ekenler & Tabatabai, 2002).

Althouhg, there was no significant correlation between the soil WFPS and enzyme activity, soil WFPS% was higher in the AF and RF systems compared to the AG in Summer 2020 and Spring 2021. It could be another reason for increased enzyme activities in the AF and RF (Figure 1). Enzymes' mobility and velocity increase by enhanced dissolution and translocation of the substrates when the soil moisture content increases (Zhang et al., 2011). Several studies reported that the soil dehydrogenase and β-glucosidase activities were positively correlated with the soil moisture content (Chendrayan et al., 1980; Tate & Terry, 1980; Dilly & Munch, 1996; Zhang et al., 2011; Wolinska & Stepniewska, 2012; Kumar et al., 2013; Furtak et al., 2020).

4. CONCLUSIONS

This study aimed to understand the functional capacity of soils under various management activities. Soil microbial community depiction and investigation of enzyme activity give a robust understanding of the effect of land management on soil quality and productivity. The extensive root system, litterfall, and higher soil porosity in non-disturbed soils of agroforestry and riparian forest systems relative to conventional row-crop agriculture improve soil microbial and enzyme activity as well as soil C and N cycling. This study revealed that RF and AF systems with higher organic matter quality and quantity contribute to the microbial biomass and selected enzyme activities. Missouri River Floodplain provides fertile soil for several agroecosystems. Efforts to incorporate optimum land management practices, which will improve soil health and sustainable use of these lands, should be considered by policymakers and farmers.

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REFERENCES

A Bear, A. D., Jones, T. H., Kandeler, E., & Boddy, L. (2014). Interactive effects of temperature and soil moisture on fungal-mediated wood decomposition and extracellular enzyme activity. *Soil Biology and Biochemistry*, *70*, 151-158. https://doi.org/10.1016/j.soilbio.2013.12.017

Acosta-Martinez, V., & Tabatabai, M. A. (2000). Enzyme activities in a limed agricultural soil. *Biology and Fertility of Soils*, *31*(1), 85-91. https://doi.org/10.1007/s003740050628

Acosta-Martinez, V., Cruz, L., Sotomayor-Ramirez, D., & Perez-Alegria, L. (2007). Enzyme activities as affected by soil properties and land use in a tropical watershed. *Applied Soil Ecology*, *35*(1), 35-45. https://doi.org/10.1016/j.apsoil.2006.05.012

Alagele, S.M., Anderson, S.H., Udawatta, R.P., Veum, K.S., & Rankoth, L.M. (2019). Effects of conservation practices on soil quality compared with a corn–soybean rotation on a claypan soil. *Journal of Environmental Quality*, 48(6), 1694-1702. https://doi.org/10.2134/jeq2019.03.0121

Alster, C. J., German, D. P., Lu, Y., & Allison, S. D. (2013). Microbial enzymatic responses to drought and to nitrogen addition in a southern California grassland. *Soil Biology and Biochemistry*, *64*, 68-79. https://doi.org/10.1016/j.soilbio.2013.03.034

Amadi, C. C., Van Rees, K. C., & Farrell, R. E. (2016). Soil–atmosphere exchange of carbon dioxide, methane, and nitrous oxide in shelterbelts compared with adjacent cropped fields. *Agriculture, Ecosystems & Environment*, 223, 123-134. https://doi.org/10.1016/j.agee.2016.02.026

Anderson, N.P., Hart, J.M., Christensen, N.W., Mellbye, M.E. & Flowers, M.D., 2010. Using the nitrogen mineralization soil test to predict spring fertilizer N rate for soft white winter wheat grown in western Oregon. Oregon State University Extension Service. https://catalog.extension.oregonstate.edu/sites/catalog/files/project/pdf/em9020.pdf

Asuming-Brempong, S., Gantner, S., Adiku, S. G. K., Archer, G., Edusei, V., & Tiedje, J. M. (2008). Changes in the biodiversity of microbial populations in tropical soils under different fallow treatments. *Soil Biology and Biochemistry*, 40(11), 2811-2818. https://doi.org/10.1016/j.soilbio.2008.08.010

Baah-Acheamfour, M., Carlyle, C. N., Bork, E. W., & Chang, S. X. (2014). Trees increase soil carbon and its stability in three agroforestry systems in central Alberta, Canada. *Forest Ecology and Management*, *328*, 131-139. http://doi.org/10.1016/j.foreco.2014.05.031

Baah-Acheamfour, M., Carlyle, C. N., Lim, S. S., Bork, E. W., & Chang, S. X. (2016). Forest and grassland cover types reduce net greenhouse gas emissions from agricultural soils. *Science of the Total Environment*, 571, 1115-1127. https://doi.org/10.1016/j.scitotenv.2016.07.106

Bailey, V. L., Fansler, S. J., Smith, J. L., & Bolton Jr, H. (2011). Reconciling apparent variability in effects of biochar amendment on soil enzyme activities by assay optimization. *Soil Biology and Biochemistry*, *43*(2), 296-301. https://doi.org/10.1016/j.soilbio.2010.10.014

Barber, N. A., Chantos-Davidson, K. M., Amel Peralta, R., Sherwood, J. P., & Swingley, W. D. (2017). Soil microbial community composition in tallgrass prairie restorations converge with remnants across a 27-year chronosequence. *Environmental Microbiology*, *19*(8), 3118-3131. http://doi.org/10.1111/1462-2920.13785

Bonanomi, G., D'Ascoli, R., Antignani, V., Capodilupo, M., Cozzolino, L., Marzaioli, R., Puopolo, G., Rutigliano, F.A., Scelza, R., Scotti, R., Rao, M.A., Zoina, A., & Zoina, A. (2011). Assessing soil quality under intensive cultivation and tree orchards in Southern Italy. *Applied Soil Ecology*, *47*(3), 184-194. http://doi.org/10.1016/j.apsoil.2010.12.007

Bordoloi, N., Baruah, K. K., & Maji, T. K. (2016). Nitrous oxide emission from a transplanted rice field in alluvial soil as influenced by management of nitrogen fertilizer. *Soil Use and Management*, *32*(4), 573-582. http://doi.org/10.1111/sum.12294

Borowik, A., & Wyszkowska, J. (2016). Soil moisture as a factor affecting the microbiological and biochemical activity of soil. *Plant, Soil and Environment*, *62*(6), 250-255. http://doi.org/10.17221/158/2016-PSE

Buyer, J. S., & Sasser, M. (2012). High throughput phospholipid fatty acid analysis of soils. *Applied Soil Ecology*, *61*, 127-130. http://doi.org/10.1016/j.apsoil.2012.06.005

Chapuis-Lardy, L. Y. D. I. E., Wrage, N., Metay, A., Chotte, J. L., & Bernoux, M. (2007). Soils, a sink for N_2O? a review. *Global Change Biology*, *13*(1), 1-17. http://doi.org/10.1111/j.1365-2486.2006.01280.x

Chendrayan, K., Adhya, T. K., & Sethunathan, N. (1980). Dehydrogenase and invertase activities of flooded soils. *Soil Biology and Biochemistry*, *12*(3), 271-273. https://doi.org/10.1016/0038-0717(80)90073-5

Culman, S. W., Snapp, S. S., Freeman, M. A., Schipanski, M. E., Beniston, J., Lal, R., Drinkwater, L.E., Laurie E. Franzluebbers, A.J., Glover, J.D., Grandy, A.S., Lee, J., Six, J., Maul, J.E., Mirksy, S.B., Spargo, J.T., & Wander, M.M. (2012). Permanganate oxidizable carbon reflects a processed soil fraction that is sensitive to management. *Soil Science Society of America Journal*, *76*(2), 494-504. http://doi.org/10.1016/0038-0717(80)90073-5

Dick, W. A. (1984). Influence of long-term tillage and crop rotation combinations on soil enzyme activities. *Soil Science Society of America Journal*, *48*(3), 569-574. http://doi.org/10.2136/sssaj1984.03615995004800030020x

Dilly, O., & Munch, J. C. (1996). Microbial biomass content, basal respiration, and enzyme activities during the course of decomposition of leaf litter in a black alder (Alnus glutinosa (L.) Gaertn.) forest. *Soil Biology and Biochemistry*, *28*(8), 1073-1081. http://doi.org/10.1016/0038-0717(96)00075-2

Divito, G. A., Rozas, H. R. S., Echeverría, H. E., Studdert, G. A., & Wyngaard, N. (2011). Long term nitrogen fertilization: Soil property changes in an Argentinean Pampas soil under no tillage. *Soil and Tillage Research*, *114*(2), 117-126. http://doi.org/10.1016/j.still.2011.04.005

Dixon, G. R., & Tilston, E. L. (Eds.). (2010). *Soil microbiology and sustainable crop production*. Springer Science & Business Media. http://doi.org/10.1007/978-90-481-9479-7

Dutaur, L., & Verchot, L.V. (2007). A global inventory of the soil CH_4 sink. *Global Biogeochemical Cycles*, *21*(4). https://doi.org/10.1029/2006GB002734

Eivazi, F. & Tabatabai, M.A., (1988). Glucosidases and galactosidases in soils. *Soil Biology and Biochemistry*, *20*(5), 601-606. https://doi.org/10.1016/0038-0717(88)90141-1

Eivazi, F., Bayan, M. R., & Schmidt, K. (2003). Select soil enzyme activities in the historic Sanborn Field as affected by long-term cropping systems. *Communications in Soil Science and Plant Analysis*, *34*(15-16), 2259-2275. https://doi.org/10.1081/CSS-120024062

Ekenler, M. (2002). *Enzyme activities in soils as affected by management practices*. Iowa State University. https://doi.org/10.31274/rtd-180813-14312

Ekenler, M., & Tabatabai, M. (2002). β-Glucosaminidase activity of soils: Effect of cropping systems and its relationship to nitrogen mineralization. *Biology and Fertility of Soils*, *36*(5), 367-376. https://doi.org/10.1007/s00374-002-0541-x

Ekenler, M., & Tabatabai, M. A. (2003). Effects of liming and tillage systems on microbial biomass and glycosidases in soils. *Biology and Fertility of Soils*, *39*(1), 51-61. https://doi.org/10.1007/s00374-003-0664-8

Evers, A. K., Bambrick, A., Lacombe, S., Dougherty, M. C., Peichl, M., Gordon, A. M., Thevathasan, N.V., Whalen, J., & Bradley, R. L. (2010). Potential greenhouse gas mitigation through temperate tree-based intercropping systems. *The Open Agriculture Journal*, 4(1). http://doi.org/10.2174/1874331501004010049

Fabrizzi, K. P., Garcia, F. O., Costa, J. L., & Picone, L. I. (2005). Soil water dynamics, physical properties, and corn and wheat responses to minimum and no-tillage systems in the southern Pampas of Argentina. *Soil and Tillage Research*, *81*(1), 57-69. http://doi.org/10.1016/j.still.2004.05.001

Franzluebbers, A. J., Chappell, J. C., Shi, W., & Cubbage, F. W. (2017). Greenhouse gas emissions in an agroforestry system of the southeastern USA. *Nutrient Cycling in Agroecosystems*, *108*(1), 85-100. https://doi.org/10.1007/s10705-016-9809-7

Frenzel, P., Rothfuss, F., & Conrad, R. (1992). Oxygen profiles and methane turnover in a flooded rice microcosm. *Biology and Fertility of Soils*, 14(2), 84-89. https://doi.org/10.1007/BF00336255

Fujii, K. (2014). Soil acidification and adaptations of plants and microorganisms in Bornean tropical forests. *Ecological Research*, *29*(3), 371-381. https://doi.org/10.1007/s11284-014-1144-3

Furtak, K., Galazka, A., & Niedzwiecki, J. (2020). Changes in soil enzymatic activity caused by hydric stress. *Polish Journal of Environmental Studies*, *29*(4). https://doi.org/10.15244/pjoes/112896

Gao, B., Ju, X., Su, F., Meng, Q., Oenema, O., Christie, P., Chen, X., & Zhang, F. (2014). Nitrous oxide and methane emissions from optimized and alternative cereal cropping systems on the North China Plain: A two-year field study. *Science of the Total Environment*, *472*, 112-124. https://doi.org/10.1016/j.scitotenv.2013.11.003

Gonzalez Mace, O., Steinauer, K., Jousset, A., Eisenhauer, N., & Scheu, S. (2016). Flood-induced changes in soil microbial functions as modified by plant diversity. *PLoS One*, *11*(11), e0166349. https://doi.org/10.1371/journal.pone.0166349

Hulicova, P., Fazekasova, D. & Fazekas, J. (2018). Impact of flooding on soil enzyme activity in environmentally sensitive areas. *Carpathian Journal of Earth and Environmental Sciences*, 13, 567-574. http://doi.org/10.26471/cjees/2018/013/048

Jarvan, M., Edesi, L., Adamson, A., & Vosa, T. (2014). Soil microbial communities and dehydrogenase activity depending on farming systems. *Plant, Soil and Environment*, *60*(10), 459-463. http://doi.org/10.17221/410/2014-PSE

Jiang, P., Anderson, S.H., Kitchen, N.R., Sadler, E.J., & Sudduth, K.A. (2007). Landscape and conservation management effects on hydraulic properties on a claypan-soil toposequence. *Soil Science Society of America Journal*, 71, 803-811 http://doi.org/10.2136/sssaj2006.0236

Klose, S., & Tabatabai, M. A. (1999). Arylsulfatase activity of microbial biomass in soils. *Soil Science Society of America Journal*, *63*(3), 569-574. http://doi.org/10.2136/sssaj1999.03615995006300030020x

Kremer, R. J., & Li, J. (2003). Developing weed-suppressive soils through improved soil quality management. *Soil and Tillage Research*, 72(2), 193-202. http://doi.org/10.1016/S0167-1987(03)00088-6

Kremer, R. J., & Hezel, L. F. (2013). Soil quality improvement under an ecologically based farming system in northwest Missouri. *Renewable Agriculture and Food Systems*, *28*(3), 245-254. http://doi.org/10.1017/S174217051200018X

Kremer, R. J., & Veum, K. S. (2015). Soil microbiota of the prairie. *Missouri Prairie Journal*, *36 (3-4)*, pp.18-21

Kremer, R. J., & Veum, K. S. (2020). Soil biology is enhanced under soil conservation management. *Soil and Water Conservation: A Celebration of*, *75*.

Kumar, S., Chaudhuri, S. & Maiti, S.K. (2013). Soil dehydrogenase enzyme activity in natural and mine soil-a review. *Middle-East Journal of Scientific Research*, *13*(7), 898-906. http://doi.org/10.5829/idosi.mejsr.2013.13.7.2801

Liang, Q., Chen, H., Gong, Y., Yang, H., Fan, M., & Kuzyakov, Y. (2014). Effects of 15 years of manure and mineral fertilizers on enzyme activities in particle-size fractions in a North China Plain soil. *European Journal of Soil Biology*, 60, 112-119. http://doi.org/10.1016/j.ejsobi.2013.11.009

Ludwig, J., Meixner, F.X., Vogel, B., & Forstner, J., (2001). Soil-air exchange of nitric oxide: An overview of processes, environmental factors, and modeling studies. *Biogeochemistry*, *52*(3), 225-257. http://doi.org/10.1023/A:1006424330555

McLaughlin, D., & Kinzelbach, W. (2015). Food security and sustainable resource management. *Water Resources Research*, 51(7), 4966-4985. http://doi.org/10.1002/2015WR017053

Merino, A., Perez-Batallon, P., & Macias, F. (2004). Responses of soil organic matter and greenhouse gas fluxes to soil management and land use changes in a humid temperate region of southern Europe. *Soil Biology and Biochemistry*, *36*(6), 917-925. http://doi.org/10.1016/j.soilbio.2004.02.006

Mishra, A., Sharma, S. D., & Khan, G. H. (2003). Improvement in physical and chemical properties of sodic soil by 3, 6, and 9 years old plantation of Eucalyptus tereticornis: Biorejuvenation of sodic soil. *Forest Ecology and Management*, *184*(1-3), 115-124. http://doi.org/10.1016/S0378-1127(03)00213-5

Montagnini, F., & Nair, P. K. R. (2004). Carbon sequestration: an underexploited environmental benefit of agroforestry systems. In *New vistas in agroforestry,* 281-295 http://doi.org/10.1023/B:AGFO.0000029005.92691.79

Moore, B. D., Kaur, G., Motavalli, P. P., Zurweller, B. A., & Svoma, B. M. (2018). Soil greenhouse gas emissions from agroforestry and other land uses under different moisture regimes in lower Missouri River Floodplain soils: A laboratory approach. *Agroforestry systems*, *92*(2), 335-348. https://doi.org/10.1007/s10457-017-0083-8

Moreno, M. V., Biganzoli, F., Casas, C., Manso, L., Moreira, E., & Silvestro, L. B. (2021). Changes in soil biological properties in different management and tillage systems in petrocalcic argiudoll. *Journal of the Saudi Society of Agricultural Sciences*, 20(2), 75-80. http://doi.org/10.1016/j.jssas.2020.12.001

Nag, S.K., Liu, R. & Lal, R. (2017). Emission of greenhouse gases and soil carbon sequestration in a riparian marsh wetland in central Ohio. *Environmental Monitoring and Assessment*, *189*(11), 1-12. https://link.springer.com/article/10.1007%2Fs10661-017-6276-9

Nathan, M. V., Stecker, J. A., & Sun, U. (2012). Soil testing in Missouri: A guide for conducting soil tests in Missouri (2012). https://mospace.umsystem.edu/xmlui/handle/10355/50590

Natural Resources Conservation Service, United States Department of Agriculture (NRCS). (2004). *Soil Survey Laboratory Methods Manual.* https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcseprd1026807.pdf.

Neira, J., Ortiz, M., Morales, L. and Acevedo, E. (2015). Oxygen diffusion in soils: Understanding the factors and processes needed for modeling. *Chilean Journal of Agricultural Research*, *75*, 35-44. http://doi.org/10.4067/S0718-58392015000300005

Oertel, C., Matschullat, J., Zurba, K., Zimmermann, F., & Erasmi, S. (2016). Greenhouse gas emissions from soils—A review. *Geochemistry*, 76(3), 327-352. http://doi.org/10.1016/j.chemer.2016.04.002

Palm, C. A., Alegre, J. C., Arevalo, L., Mutuo, P. K., Mosier, A. R., & Coe, R. (2002). Nitrous oxide and methane fluxes in six different land use systems in the Peruvian Amazon. *Global Biogeochemical Cycles*, 16(4), 21-1. http://doi.org/10.1029/2001GB001855

Palma, J. H., Graves, A. R., Bunce, R. G. H., Burgess, P. J., De Filippi, R., Keesman, K. J., Van Keulen, H., Liagre, F., Mayus, M., Moreno, G., Reisner, Y., & Herzog, F. (2007). Modeling environmental benefits of silvoarable agroforestry in Europe. *Agriculture, Ecosystems & Environment*, 119(3-4), 320-334. https://doi.org/10.1016/j.agee.2006.07.021

Parham, J.A., and Deng, S.P. (2000). Detection, quantification, and characterization of β-glucosaminidase activity in soil. *Soil Biology and Biochemistry*, *32*(8-9), 1183-1190. https://doi.org/10.1016/S0038-0717(00)00034-1

Pascual, J. A., Garcia, C., Hernandez, T., Moreno, J. L., & Ros, M. (2000). Soil microbial activity as a biomarker of degradation and remediation processes. *Soil Biology and Biochemistry*, *32*(13), 1877-1883. http://doi.org/10.1016/S0038-0717(00)00161-9

Paudel, B. R., Udawatta, R. P., Kremer, R. J., & Anderson, S. H. (2012). Soil quality indicator responses to row crop, grazed pasture, and agroforestry buffer management. *Agroforestry Systems*, *84*(2), 311-323. http://doi.org/10.1007/s10457-011-9454-8

Paustian, K., Six, J., Elliott, E. T., & Hunt, H. W. (2000). Management options for reducing CO_2 emissions from agricultural soils. *Biogeochemistry*, *48*(1), 147-163. http://doi.org/10.1023/A:1006271331703

Rachman, A., Anderson, S. H., & Gantzer, C. J. (2005). Computed-tomographic measurement of soil macroporosity parameters as affected by stiff-stemmed grass hedges. *Soil Science Society of America Journal*, *69*(5), 1609-1616. http://doi.org/10.2136/sssaj2004.0312

Salazar, S., Sanchez, L. E., Alvarez, J., Valverde, A., Galindo, P., Igual, J. M., Peix, A., & Santa-Regina, I. (2011). Correlation among soil enzyme activities under different forest system management practices. *Ecological Engineering*, *37*(8), 1123-1131. http://doi.org/10.1016/j.ecoleng.2011.02.007

Sauer, T. J., Cambardella, C. A., & Brandle, J. R. (2007). Soil carbon and tree litter dynamics in a red cedar–scotch pine shelterbelt. *Agroforestry Systems*, *71*(3), 163-174. http://doi.org/10.1007/s10457-007-9072-7

Seobi, T., Anderson, S. H., Udawatta, R. P., & Gantzer, C. J. (2005). Influence of grass and agroforestry buffer strips on soil hydraulic properties for an Albaqualf. *Soil Science Society of America Journal*, *69*(3), 893-901. http://doi.org/10.2136/sssaj2004.0280

Stott, D. E., Andrews, S. S., Liebig, M. A., Wienhold, B. J., & Karlen, D. L. (2009). Evaluation of β-glucosidase activity as a soil quality indicator for the soil management assessment framework. S*oil Science Society of America Journal*, *74*(1), 107-119 http://doi.org/10.2136/sssaj2009.0029

Tabatabai, M. A. (1994). Soil enzymes. *Methods of Soil Analysis: Part 2 Microbiological and Biochemical Properties, 5*, 775-833. framework.

Tate, R.L., & Terry, R.E. (1980). Variation in microbial activity in histosols and its relationship to soil moisture. *Applied and Environmental Microbiology*, *40*(2), 313-317. http://doi.org/10.1128/AEM.40.2.313-317.1980

Topp, G.C., & Ferre, P.A. (2002). Water content. In Methods of Soil Analysis Part 4, Physical Methods, Dane J.H. &Topp G.C. (eds). *Soil Science Society of America*, *417-545*

Udawatta, R. P., Anderson, S. H., Gantzer, C. J., & Garrett, H. E. (2006). Agroforestry and grass buffer influence on macropore characteristics: A computed tomography analysis. *Soil Science Society of America Journal*, *70*(5), 1763-1773. http://doi.org/10.2136/sssaj2006.0307

Udawatta, R.P., Anderson, S.H., Gantzer, C.J., & Garrett, H.E. (2008). Influence of prairie restoration on CT-measured soil pore characteristics. *Journal of Environmental Quality*, *37*(1), 219-228. http://doi.org/10.2134/jeq2007.0227

Udawatta, R. P., Kremer, R. J., Garrett, H. E., & Anderson, S. H. (2009). Soil enzyme activities and physical properties in a watershed managed under agroforestry and row-crop systems. *Agriculture*, *Ecosystems and Environment*, *131*(1-2), 98-104. http://doi.org/10.1016/j.agee.2008.06.001

Ussiri, D.A., Lal, R. & Jarecki, M.K. (2009). Nitrous oxide and methane emissions from long-term tillage under a continuous corn cropping system in Ohio. *Soil and Tillage Research*, *104*(2), 247-255. http://doi.org/10.1016/j.still.2009.03.001

Vallejo, V. E., Roldan, F., & Dick, R. P. (2010). Soil enzymatic activities and microbial biomass in an integrated agroforestry chronosequence compared to monoculture and a native forest of Colombia. *Biology and Fertility of Soils*, *46*(6), 577-587. http://doi.org/10.1007/s00374-010-0466-8

Vanhala, P. (2002). Seasonal variation in the soil respiration rate in coniferous forest soils. *Soil Biology and Biochemistry*, *34*(9), 1375-1379. http://doi.org/10.1016/S0038-0717(02)00061-5

Verchot, L. V., & Borelli, T. (2005). Application of para-nitrophenol (pNP) enzyme assays in degraded tropical soils. *Soil Biology and Biochemistry*, *37*(4), 625-633. http://doi.org/10.1016/j.soilbio.2004.09.005

Veum, K. S., Goyne, K. W., Holan, S. H., & Motavalli, P. P. (2011). Assessment of soil organic carbon and total nitrogen under conservation management practices in the Central Claypan Region, Missouri, USA. *Geoderma*, *167*, 188-196. http://doi.org/10.1016/j.geoderma.2011.09.003

Veum, K. S., Goyne, K. W., Kremer, R. J., Miles, R. J., & Sudduth, K. A. (2014). Biological indicators of soil quality and soil organic matter characteristics in an agricultural management continuum. *Biogeochemistry*, *117*(1), 81-99. http://doi.org/10.1007/s10533-013-9868-7

Veum, K. S., Lorenz, T. L., & Kremer, R. J. (2018). Microbial community structure in Missouri prairie soils. *Missouri Prairie Journal*, *39*, 18-20.

Wallenius, K., Rita, H., Mikkonen, A., Lappi, K., Lindström, K., Hartikainen, H., Raateland, A., & Niemi, R. M. (2011). Effects of land use on the level, variation, and spatial structure of soil enzyme activities and bacterial communities. *Soil Biology and Biochemistry*, *43*(7), 1464-1473. http://doi.org/10.1016/j.soilbio.2011.03.018

Wang, X., Qi, J. Y., Zhang, X. Z., Li, S. S., Virk, A. L., Zhao, X., Xiao, X.P., & Zhang, H. L. (2019). Effects of tillage and residue management on soil aggregates and associated carbon storage in a double paddy cropping system. *Soil and Tillage Research*, *194* http://doi.org/10.1016/j.still.2019.104339

Weerasekara, C., Udawatta, R. P., Jose, S., Kremer, R. J., & Weerasekara, C. (2016). Soil quality differences in a row-crop watershed with agroforestry and grass buffers. *Agroforestry Systems*, *90*(5), 829-838. https://link.springer.com/article/10.1007/s10457-016-9903-5

Weil, R. R., Islam, K. R., Stine, M. A., Gruver, J. B., & Samson-Liebig, S. E. (2003). Estimating active carbon for soil quality assessment: A simplified method for laboratory and field use. *American Journal of Alternative Agriculture*, *18*(1), 3-17. http://doi.org/10.1079/AJAA200228

Weitao, L.I., Meng, W.U., Ming, L.I.U., Jiang, C., Xiaofen, C.H.E.N., Kuzyakov, Y., Rinklebe, J. & Zhongpei, L.I. (2018). Responses of soil enzyme activities and microbial community composition to moisture regimes in paddy soils under long-term fertilization practices. *Pedosphere*, *28*(2), 323-331. http://doi.org/10.1016/S1002-0160(18)30005-5

Wolinska, A., & Stępniewska, Z. (2012). Dehydrogenase activity in the soil environment. *Dehydrogenases*, *10*, 183-210. http://doi.org/10.5772/48294

Xavier, C. V., Moitinho, M. R., Teixeira, D. D. B., de Araujo Santos, G. A., de Andrade Barbosa, M., Milori, D. M. B. P., Rigobelo, E., Cora, J.E., & Junior, N. L. S. (2019). Crop rotation and succession in a no-tillage system: implications for CO_2 emission and soil attributes. *Journal of environmental management*, *245*, 8-15. http://doi.org/10.1016/j.jenvman.2019.05.053

Yuan, X., Lin, X., Chu, H., Yin, R., Zhang, H., Hu, J. and Zhu, J. (2006). Effects of elevated atmospheric CO_2 on soil enzyme activities at different nitrogen application treatments. *Acta Ecologica Sinica*, *26*(1), 48-53. http://doi.org/10.1016/S1872-2032(06)60005-X

Zhang, Y., Chen, L., Wu, Z., & Sun, C. (2011). Kinetic parameters of soil β-glucosidase response to environmental temperature and moisture regimes. *Revista Brasileira de Ciancia do Solo*, *35*(4), 1285-1291. http://doi.org/10.1590/S0100-06832011000400022