Pecan agroforestry systems improve soil quality by stimulating enzyme activity (#63189)

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Pecan agroforestry systems improve soil quality by stimulating enzyme activity

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Background. In response to an ever-growing global human population, the benefits of agroforestry systems include optimized land utilization and the promotion of stand growth. However, the specific growth promotion mechanisms remain unclear; thus, the relationships between enzyme activities and the physicochemical properties of soils warrant further study. This study aimed to explore the impacts of different agroforestry models on soil moisture, ~~soil~~ nutrients, ~~and soil~~ enzyme activities and ~~the~~ formation of a mechanism that drives the organic combination of multi-industries. **Methods.** The treatments for this study included a single cultivation (CK) pecan control and three agroforestry systems (pecan + *Paeonia suffruticosa* + *Hemerocallis citrina* (PPH), pecan + *Paeonia suffruticosa* (PPS), and pecan + *Paeonia lactiflora*Pa (PPL)). Soil samples were divided according to the sampling depth (0-20cm, 20-40cm, 40-60cm). **Results.** The pecan agroforestry system significantly improved the physical properties of the pecan plantation soil, enriched the soil nutrients, and the activities of soil enzymes related to C, N, and P cycles ~~were increased~~. Compared with the pecan monoculture, the bulk density of the pecan agroforestry system (PPH and PPL) ~~soil~~ was reduced by 16.13% and 7.10%, the soil moisture content and total soil porosity increased, while improvements in the physical properties of the PPS agroforestry system ~~soil~~ was not obvious. Following agroforestry, the soil TP, TN, AK, and TC increased significantly, while the soil S-UE, S-AKP, and S-NAG enzyme activities also increased significantly. The results demonstrated that agroforestry systems could improve the physicochemical properties and enzyme activities of pecan orchard soils to some extent; thus, for different agroforestry models, root interactions and the microbial compositions of different intercropping plants should be taken into consideration.

Pecan Agroforestry Systems Improve the Soil Quality by Stimulating the Enzyme Activity

Effects of Pecan Agroforestry Systems of soil

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Abstract

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Keywords Pecan, Agroforestry, Soil nutrients, Enzyme activity

Introduction

Agroforestry is a sustainable land management measure applied to maintain soil fertility and productivity (Dollinger & Jose, 2018; Isbell et al., 2017), as the combination of tree and crop systems optimize resource planting areas more effectively than individual tree systems (Torralba et al., 2016). It can promote the creation of jobs/generation of income while protecting biodiversity and ecosystem services (Muchane et al., 2020; Santos et al., 2019). Domestic and foreign research reports have shown that, in contrast to monocultures, agroforestry intercropping can promote a variety of agroecosystem services by increasing yields, while improving soil quality and soil carbon sequestration (Cong et al., 2015; Paul et al., 2018). Agroforestry is also beneficial for the maintenance of soil organic carbon and total nitrogen (Lian et al., 2019; Lu et al., 2015). The physical properties (Chen et al., 2019), levels of available soil nutrients (N and P), and enzymes (urease and acid phosphatase) were also found to improve (Q. S. Li et al., 2018; Tang et al., 2020).

Pecans require large cultivation areas and extended growing periods. In China, pecans are extensively planted in Anhui, which is considered to be one of the best planting areas (R. Zhang et al., 2015). In agroforestry systems, pecan plantations are typically intercropped with other cash crops, such as traditional Chinese medicine and fruits. The transition from pecan monocultures to agroforestry systems is based on the capacity of pecans to improve soil quality, soil fertility, and the potential sustainability of farmlands (Gao et al., 2019; Sagastuy & Krause, 2019).

Soil comprises the foundation of terrestrial ecosystems, where cumulatively, its functions and microbial characteristics can alter environments on a global scale (Rillig et al., 2019; Wilson & Lovell, 2016). The physicochemical properties (Chen et al., 2019) and enzyme activity (Wang et al., 2017) of soils are typically considered important indicators of soil quality (Paz-Ferreiro & Fu, 2016). The properties of soils, such as the availability of nutrients and enzyme activity typically vary with soil depth (Chen et al., 2017), which leads to variable relative qualities of topsoil and subsoil factors. Woody crops such as peony for oil, herbaceous peony with medicinal value, and day lily are widely planted across North Subtropical China based on ecological and economic profitability. These crops were found to be the best cash crops for intercropping (Yu-zhen et al., 2018).

In recent years, cultivation techniques (Luo et al., 2016), nut quality (Atanasov et al., 2018), the chemical constituents of plant fruits (Fernandes et al., 2017), as well as the components and utilization of fruit shells

(Martinez-Casillas et al., 2019) have been extensively investigated. However, there are few studies on the interaction between soil nutrients and soil enzyme activity under different agroforestry patterns of *Carya cathayensis* introduced in northern subtropical China. We speculated that the agroforestry management of pecans has certain impacts on soil quality. Thus, to elucidate the effects of the management of pecan compounds on soil quality (particularly its physical and chemical properties and enzyme activity), three agroforestry systems (PPH, PPS, and PPL) and a pecan monoculture (CK) were selected for comparison.

Differences in the physical properties of soils under different agroforestry models were compared by measuring their electrical conductivity, moisture content, bulk density, and total porosity. The chemical properties of the soil pH, total C, N, P, K, Ca, Mg, and available N, P, and K were determined, as well as the changes of soil nutrients under different agroforestry patterns. The activity of seven topsoil enzymes (e.g., urease (S-UE), alkaline phosphatase (S-AKP), polyphenol oxidase (S-PPO), cellobiohydrolase (S-CBH), 1,4-β-N-acetylglucosamines (S-NAG), peroxidase (S-POD), and β-1,4-glucosidase (S-BG)) were determined.

Our hypothesis was as follows. Firstly, the soil structure of pecan monocultures is poor and the nutrient content is low. Secondly, different agroforestry systems can improve the physical properties of the soil, optimize its structure, and enrich its nutrients to a certain extent. Finally, the enzyme activity in soils of different pecan agroforestry intercropping systems were higher than that of monoculture systems.

Materials & Methods

Experimental site description and design

The study was conducted at a pecan orchard base in Wenji Town, Yingquan District, China (115°36'E,33° 3'N). This area is home to a warm temperate semi-humid monsoon climate, with an annual average temperature of 14.9℃ and average annual precipitation of 889 mm. The extreme maximum temperature was 41.4℃, whereas the extreme minimum temperature was -20.4℃.

The afforestation time of the experimental site was 2016, the variety was 'Pawnee', the seedling age was three years, and the row spacing was 4.0m × 6.0 m. In 2017, three types of perennials (*Paeonia suffruticosa*, *Hemerocallis citrina*, and *Paeonia lactiflora* Pall) were planted in the pecan forest. In September 2019, a randomized block design was adopted, which consisted of four treatments and three repeats. The treatments included: (1) PPH, the row spacing of *Paeonia suffruticosa* was 0.2 m × 0.2 m and that of *Hemerocallis citrina* was 0.4 m × 0.8 m; (2) PPS, the row spacing of *Paeonia suffruticosa* was 0.2 m × 0.6 m; (3) PPL, the row spacing of *Paeonia lactiflora* PPL was 0.2 m × 0.6 m; (4) pecan pure forest (CK).

Soil sampling

Soil samples were collected from the experimental site in September 2019. Eight pecan seedlings represented one plot, and three plots were randomly established for each treatment in the selected sampling area. For each plot, a shovel was used to remove plants and their litter from the surface. According to the "S" sampling method, five random soil profiles were obtained, where 0~20cm, 20~40cm, and 40~60cm soil samples were collected, ~~from bottom to top~~. The samples were then mixed to generate a soil sample for each layer. A total of 36 soil samples were collected from the four treatment sites, which were sealed in plastic bags and transported to the laboratory. Following sieving (2 mm mesh size), some of the fresh soil samples were packed in sealed bags and refrigerated at 4°C for the subsequent determination of their physical and chemical properties, while the remaining soil samples were placed in bags, dried, and screened to determine their enzyme activity.

Soil physicochemical properties analysis

Soil samples were collected via the ring knife method to determine their water content (MC), bulk density (BD), and porosity (TPO). Following the removal of impurities, the nitrate-nitrogen (NO_3^--N), ammonium nitrogen (NH_4^+-N), available phosphorus (AP), available potassium (AK), pH value, electrical conductivity value (EC), total phosphorus (TP), total potassium (TK), total carbon (TC), total nitrogen (TN), K, Ca, and Mg contents were determined. The soil NO_3^--N, NH_4^+-N, TP, AP, and AK were measured using an automatic discontinuous chemical analyzer (CleverChem Anna, Germany). The pH value of the soil was measured using a pH meter in a 1:2.5 (w/v) aqueous solution (X. P. Zhang et al., 2019), whereas the EC value of the soil was determined using an electrical conductivity meter in a soil-water extract at 1:5 at 25℃. The TC and TN of the soil were determined via an automatic element analyzer (Vario EL Cube, Germany Elementar). The contents of K, Ca, and Mg in the soil were measured using an inductively coupled Plasma Emission Spectrometer (iCAP 6300 Series, America Thermo Fisher).

Soil enzyme activity

After the fresh soil samples of the surface layer (0-20cm) were air-dried and sifted through a 50 mesh, the activity of seven types of soil enzymes, including peroxidase (S-POD), polyphenol oxidase (S-PPO), urease (S-UE), alkaline phosphatase (S-AKP), β-1,4-glucosidase (S-BG), cellobiohydrolase (S-CBH), and 1,4-β-N-acetylglucosaminidase (S-NAG) were studied and determined by Shanghai Optimal Biotechnology Co., Ltd. using the corresponding kit. The value employed was the international unit of enzyme consumption per gram of soil (U/g).

Statistical analysis

SPSS 19.0 and Origin Pro 2021 software was used to analyze the comprehensive data. The data derived from the different soil depths (0-20cm, 20-40cm, and 40-60cm) were statistically analyzed by single-factor analysis of variance (ANOVA), whereas significant differences ($P<0.05$) in the physical and chemical properties of the soils of the various agroforestry systems were evaluated using a minimum significant difference test (LSD). Correlation analysis was employed to examine the relationships between the physical and chemical properties of the different soil layers, as well as between the physical and chemical properties and enzyme activity in the topsoil (0-20cm).

The PCA ranking method was used to analyze the physical and chemical properties of the soil.

Results

Soil physical properties

The basic physical properties of the soil samples extracted from different soil depths and agroforestry patterns of pecan, including the EC, MC, BD, and TPO are shown in Fig. 1. In the 0-20 cm soil layer, the electrical conductivity of PPL and PPS was significantly higher than that of the PPS and CK ($P < 0.05$). The soil water content of the PPS group was significantly higher than that of the CK ($P < 0.05$). The soil bulk density of all the soil samples ranged from 1.42 g/cm^3 to 1.55 g/cm^3. The soil bulk density of the PPS and CK was significantly higher than that of the PPH and PPL ($P < 0.05$). There was a negative correlation between the total soil porosity and bulk density, where the higher the bulk density value, the lower the total soil porosity.

In the 20-40 cm soil layer, the electrical conductivity of the CK group soil was the lowest. The moisture content of the soil samples from the CK and PPS groups was significantly higher than that of the PPH and PPL groups ($P<0.05$). The bulk density of all the soil samples ranged from 1.39 g/cm^3 to 1.71 g/cm^3

In the 40-60 cm soil layer, the electrical conductivity of the PPL soil was significantly higher than that of the CK, PPH, and PPS ($P < 0.05$). The soil moisture content of the PPS group was significantly higher than that of the CK group ($P < 0.05$). The difference in the soil moisture content between the PPH and PPS groups was significant ($P < 0.05$). The bulk density of all the soil samples ranged from 1.02 g/cm^3 to 1.68 g/cm^3, and changes in the bulk density of the 20-40 cm and 40-60 cm soil layers were consistent with changes in the topsoil (0-20 cm).

Soil chemical properties

In the same soil layers, there were some variations in the chemical properties of the different agroforestry systems (Table 1 and Fig. 2). Compared with the CK group, the agroforestry system increased the content of some elements in the soil. There were significant differences in the NO_3^--N, TN, AK, TK, and TC contents between the four pecan agroforestry systems. The average pH value of all soil layer samples ranged from 7.80 to 8.40, and the pH decreased by from 0.96% - 2.41% in contrast to the monoculture. The content of Ca and Mg in the PPS group was significantly higher than that in the PPH, PPL, and CK groups ($p < 0.05$).

Moreover, the TP and TN contents in the 0-20 cm soil layer of the CK group were significantly lower than those of the PPS and PPL groups ($p < 0.05$). The contents of AP, NH_4^+-N, AK, and TC in the CK group were lower than that of the soil following agroforestry. There were significant differences in the soil NO_3^--N between the PPL and the PPH, PPS, and CK groups ($p < 0.\ 05$). The TK content of the PPS group soil was significantly higher than that of the PPH, PPL, and CK groups ($p < 0.05$).

Correlation study of soil physical and chemical properties in different soil layers

Fig. 3 summarizes the correlations between the main physical and chemical properties of the treatments in the different soil layers (0-20 cm, 20-40 cm, and 40-60 cm). The results revealed that in the 0-20 cm soil layer, the EC was negatively correlated with the BD and Ca content ($P < 0.05$), and positively correlated with the TPO ($P < 0.05$). Further, the BD was positively correlated with the Ca and Mg contents ($P < 0.001$). The AP was positively correlated with the TP, AK, and TC ($P<0.05$). The TP and AK were positively correlated with the available TN and TC ($P < 0.05$). There was a significantly positive correlation between the total nitrogen (TN) and total carbon (TC) ($P < 0.001$), as well as between the pH and total carbon Ca content ($P < 0.05$).

In the 20-40 cm and 40-60 cm soil layers, there was a very significant positive correlation between the soil EC and NO_3^--N. The soil MC and BD were significantly correlated with the TPO, and positively correlated with the TK, TC, Ca, and Mg contents ($P < 0.001$). The soil BD was negatively correlated with the NH_4^+-N and positively correlated with the TK ($P < 0.05$), whereas the TP was positively correlated with the Ca and Mg contents ($P < 0.05$). There was a significantly positive correlation between the TK and TN, TC, Ca, and Mg contents ($P < 0.05$), as well as between the AK and TN ($P < 0.05$). Further, there was a very significant positive correlation between then TN and TC, Ca, and Mg contents ($P < 0.001$), and an extremely significant positive correlation between the Ca and Mg contents ($P < 0.001$).

Soil enzyme activity

There were significant differences in the urease (S-UE) activity between the PPS, PPL, and CK agroforestry systems in the 0-20cm soil layer. The activity of alkaline phosphatase (S-AKP) and 1-β-N-acetylglucosaminidase (S-NAG) in the CK soil were significantly lower than those of the other agroforestry systems ($p < 0.05$). The activity of polyphenol oxidase (S-PPO) and cellobiohydrolase (S-CBH) in the PPS were significantly lower than those in the CK group ($p < 0.05$). The activity of peroxidase (S-POD) and β-1,4-glucosidase (S-BG) in the PPL were significantly lower than those in the CK group ($p < 0.05$).

Study of the relationships between soil physicochemical properties and soil enzyme activity

The S-AKP was positively correlated with the MC, TP, AK, TN, and TC ($P <0.05$). The S-PPO was negatively correlated with the BD, TP, and Mg contents ($P <0.05$). The S-CBH was positively correlated with the NH_4^+-N and AK. There was a significantly negative correlation between the TN and TC ($P <0.05$). However, the S-NAG was positively correlated with the AP, AK, TN, and TC ($P <0.05$). The S-POD and S-BG had a significantly negative correlation with the EC ($P<0.05$). Further, the S-POD had a significantly positive correlation with the Ca content ($P<0.05$), and the S-BG had a significantly negative correlation with the NO_3^--N ($P<0.05$).

Principal component analysis of soil physical and chemical properties

Table 4 shows the weights of the 15 original variables along with the first four principal components. According to the PCA ranking results, the eigenvalues of the first four ranking axes were greater than 1, and the cumulative contribution rate reached 81.55% (Fig. 4, Table 3). The main axis (PC1) contributed 32.93% of the total variance, the second principal component (PC2) explained 28.09% of the total variance, the third principal component (PC3) contributed 11.55% to the total variance, and the fourth principal component (PC4) contributed 8.98% to the total variance.

Discussion

The effect of agroforestry system on the physicochemical properties of pecan soil

As we assumed, compared with CK, pecan agroforestry systems (PPH and PPL) were shown to reduce the bulk density, increase the moisture content, and increase the total porosity of the soil. These results were consistent with previous studies(Chen et al., 2019; Stöcker et al., 2020). Due to the decomposition of litter and chemical degradation of minerals, the soil EC level increased following agroforestry (Samani et al., 2020). In this study, EC levels in the surface layer (0-20 cm) and subsurface layer (20-40 cm) of the soil increased after the agroforestry of pecans. Compared with the CK, the EC levels decreased in the deeper soil layer (40-60 cm) after agroforestry. This may have been related to the distribution of the root systems and biochemical cycles of pecan (Pierret et al., 2016). The vertical roots of pecan plants are concentrated below 40 cm (Xu et al., 2019), whose taproot depth is much greater than that of intercropped plants (Hanson, 2019).

Making good use of agricultural intercropping to improve soil fertility has been well documented in earlier studies (Du et al., 2019; Xia et al., 2019). We found that agroforestry increased the nutrient content, improved nutrient utilization, and promoted nutrient cycling in the soil (Mortimer et al., 2018). These results may have been due to other mechanisms, such as changes in community composition and biomass, organic matter inputs, and the microclimate or soil structure (Borden et al., 2019; Wu et al., 2020). In this study, most of the soil nutrients (e.g., AP, TP, NH_4^+-N, AK, TN, TC) measured in the ~~surface~~ soil of the pecan agroforestry systems (PPH, PPS, and PPL) and pure pecan forest (CK) were increased. Additionally, PPS increased the Ca and Mg content at the average depth of the soil. Therefore, pecan intercropping improved the availability of soil nutrients to a certain extent.

The pH of the soil affects the acid-base balance of microbial cells and regulates the utilization of soil nutrients (Kemmitt et al., 2006). In this study, the soil pH value was lower at the surface layer (0-20 cm) than the deeper soil layers; however, it did not change significantly, which was consistent with the results of Andrianarisoa et al. (2016). After planting crops in the pecan forest, the soil pH was lower than that of the pecan monocropping, which indicated that agroforestry can improve the soil pH, prevent excessive soil alkalization, and maintain soil productivity and aligned with the findings of Hu et al. (2019). Changes in the physicochemical properties of soil caused by the intercropping of different Chinese herbal medicines may have been partly due to differences in the distribution of plant-soil roots and litter cover in the pecan agroforestry systems (Cardinael et al., 2020; Q.-s. LI et al., 2016).

Different effects of agricultural and forest intercropping on enzyme activity in the surface soil of pecan forests

Furthermore, enzyme activity was a critical index of soil fertility and quality and played an important role in the soil's biochemical function (Nannipieri et al., 2018). In our research, some of the enzyme activity in the agroforestry cultivation of pecans were significantly higher than those of the single cultivation of pecans, which was consistent with the findings of other intercropping systems (Clivot et al., 2019; Ma et al., 2017). Thus, a better understanding of these seven enzymes can more effectively clarify the role of agroforestry systems toward improving soil fertility. Soil urease (S-UE), β-1,4-glucosidase (S-BG), cellobiohydrolase (S-CBH), 1,4-β-N-acetylglucosaminidase (S-NAG), and alkaline phosphatase (S-AKP) are all hydrolases. Among them, S-BG and S-CBH are involved in the C cycle, S-UE and S-NAG are involved in the N cycle, and S-AKP participates in the P cycle (Adetunji et al., 2017; T. Li et al., 2019). Oxidoreductase was involved in the synthesis of soil humus components and in the process of soil formation, which helps to understand the nature of soil occurrence and related soil fertility (Ananbeh et al., 2019). In the present study, peroxidase (S-POD) and polyphenol oxidase (S-PPO) were oxidoreductases.

Our research found that in the surface soil, in contrast to the CK, the S-UE, S-AKP, and S-NAG activity of the agroforestry system were significantly increased. However, the S-BG and S-POD activity of PPL intercropping, compared with the CK, significantly declined, which may have been attributed to the fact that soil moisture affects the biochemical process of soil carbon conversion catalyzed by S-BG (Y. Zhang et al., 2011). When soil moisture decreases, the S-BG enzyme activity will be reduced to a certain extent, which reduces the nutrient renewal speed and lowers the supply of plant nutrients(Adetunji et al., 2017). Compared with CK, the S-PPO and S-CBH activity in PPS intercropping were significantly decreased. This may have been due to the competition and interaction between different species under different compound management modes (particularly root system and root exudates), which affected crop water and nutrient absorption (Karaca et al., 2010).

In this study, the activity of surface soil enzymes were closely related to the distribution of soil C, N, and P in various systems, which confirmed the key roles of these soil enzymes in carbon and nitrogen cycling in the ambient environment (Philippot et al., 2013). The AK, TN, and TC contents were highly correlated with the activity of S-AKP, S-CBH, and S-NAG, and had the strongest correlation with S-NAG enzyme activity, which better explained the changes in S-NAG enzyme activity. TP was highly positively correlated with S-AKP, which indicated that TP was the main factor that directly or indirectly influenced the activity of S-AKP, which may have been due to its positive feedback effect. Although the roles of some enzymes we studied in the nutrient cycle were not evident, their ability to promote the decomposition of plant litter appeared to explain the increased content of these elements in the soil, as we expected theoretically ((Feng et al., 2019).

Conclusions

Our research investigated the impacts on soil quality associated with the conversion of pecans from a single crop to agroforestry. The purpose of the study was to elucidate how pecans can benefit from intercropping in young forests, particularly as relates to the improvement of physicochemical properties and enzyme activity. The results revealed that compared with pecan monocropping, the agroforestry systems were beneficial for improving the physical properties of the soil and optimizing the soil structure. Moreover, the test results showed that intercropping had a certain effect on soil nutrients, improved nutrient utilization efficiency, and increased soil enzyme activity to promote soil C, N, and P nutrient cycling. Therefore, these systems can be incorporated for sustainable soil management practices, so that farmers can obtain the best use of resources on limited land area. Our research results have significant implications for the development and management of pecan agroforestry systems. This study can facilitate the maintaining of balance in the agroforestry systems; however, it is also necessary to conduct further in-depth studies on the root distribution and enzyme activity of intercropping plants, to correlate their changes with microbial composition, while understanding their regulatory mechanisms.

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Table 1 (on next page)

Basic chemical properties of soils in various agroforestry systems in different soil layers

The lowercase letters of different agroforestry systems in the same soil layer were different, and the difference was significant ($P < 0.05$).

Treatments	AP (mg/kg)	TP (g/kg)	NH_4^+-N (mg/kg)	NO_3^--N (mg/kg)	TN (g/kg)	AK （mg/kg）	TK (g/kg)	TC (g/kg)
0-20cm								
PPH	9.99±2.13a	1.72±0.14ab	0.69±0.36a	2.34±1.21b	0.94±0.12a	244.27±55.22a	3.18±0.42b	16.40±1.62a
PPS	10.42±1.47a	1.98±0.37a	0.61±0.52a	1.76±0.78b	0.94±0.04a	223.70±61.20a	4.15±0.33ab	16.54±0.42a
PPL	8.43±1.81a	1.84±0.23a	0.38±0.14a	6.08±2.28a	0.87±0.03a	78.37±25.26b	4.47±0.79a	14.70±0.10ab
CK	6.76±3.21a	1.29±0.26b	0.14±0.11a	2.52±0.84b	0.48±0.25b	52.93±7.90b	4.34±0.80ab	13.63±1.00b
20-40cm								
PPH	3.58±1.73a	0.98±0.02a	0.89±0.35a	2.82±1.92b	0.35±0.03b	149.20±42.52a	2.51±0.31c	12.09±0.16b
PPS	2.19±0.90a	1.15±0.04a	0.32±0.04b	0.57±0.08b	0.60±0.05a	147.90±11.89a	4.89±0.35a	16.44±0.73a
PPL	3.05±2.73a	1.12±0.16a	0.47±0.15b	7.85±3.12a	0.42±0.11b	119.67±27.14a	4.04±0.67b	13.17±0.61b
CK	1.51±0.25a	1.01±0.08a	0.21±0.12b	2.57±1.31b	0.29±0.06b	28.43±3.76b	3.73±0.23b	12.79±0.80b
40-60cm								
PPH	2.25±1.07a	0.96±0.07a	0.60±0.10a	2.14±0.96b	0.21±0.04b	97.60±40.45ab	2.17±0.48b	11.39±0.19b
PPS	1.25±0.46a	1.10±0.06a	0.29±0.20b	0.56±0.25b	0.37±0.06a	113.27±23.08a	4.76±1.25a	19.68±0.62a
PPL	1.32±0.08a	1.07±0.22a	0.28±0.10b	9.76±2.33a	0.25±0.11ab	58.10±25.75bc	3.52±0.95ab	12.52±1.98b
CK	2.58±2.85a	0.92±0.05a	0.16±0.14b	2.28±1.00b	0.18±0.06b	16.50±5.93c	3.36±0.26ab	10.85±0.18b

Table 2(on next page)

Activities of seven main enzymes in the topsoil of different pecan agroforestry systems

S-UE, urease; S-AKP, alkalinephosphatase; S-PPO, polyphenoloxidase; S-CBH, cellobiohydrolase; S-NAG, 1,4-β-N-acetylglucosaminidase; S-POD, peroxidase; S-BG, β-1,4-glucosidase. The lowercase letters of different agroforestry systems in the same soil layer were different, and the difference was significant ($P < 0.05$).

Treatment	S-UE (U/g)	S-AKP (U/g)	S-PPO (U/g)	S-CBH (U/g)	S-NAG (U/g)	S-POD (U/g)	S-BG (U/g)
PPH	893.89±15.12bc	10.77±0.57a	12.22±0.62a	4.46±0.46b	6.59±1.38a	4.60±0.99ab	129.58±29.45a
PPS	1018.64±67.09a	11.72±0.53a	9.76±0.43b	5.43±0.91b	7.14±0.38a	4.91±0.76ab	131.77±19.53a
PPL	974.79±54.41ab	10.86±0.98a	10.85±0.63ab	11.18±2.83a	3.13±0.79b	3.38±1.16b	24.84±6.50b
CK	831.98±33.33c	8.48±0.49b	11.50±1.39a	12.52±2.12a	2.39±0.58b	5.35±0.50a	150.84±16.58a

Table 3(on next page)

Pearson correlation coefficient between soil physical and chemical properties and soil enzyme activities in 0-20 cm soil layer

*Significance is at p<0.05

**Significance is at p<0.01

***Significance is at p<0.001

Soil physical and chemical properties include EC, MC, BD, TPO, AP, TP, NH_4^+- N, **NO_3^--N**, TK, AK, TN, TC, soil pH, Ca and Mg. Soil enzyme activities include S-UE, S-AKP, S-PPO, S-CBH, S-NAG, S-POD, S-BG.

	S-UE	S-AKP	S-PPO	S-CBH	S-NAG	S-POD	S-BG
EC	0.322	0.411	0.182	-0.150	0.047	-0.681*	-0.648*
MC	0.530	0.634*	-0.265	-0.284	0.503	0.180	-0.292
BD	0.180	0.031	-0.653*	-0.043	0.156	0.357	0.484
TPO	-0.180	-0.032	0.654*	0.043	-0.156	-0.356	-0.483
AP	0.415	0.466	-0.345	-0.305	0.732**	0.158	-0.084
TP	0.432	0.691*	-0.643*	-0.357	0.512	-0.050	-0.358
NH_4^+-N	0.495	0.425	0.207	-0.678*	0.572	-0.410	0.032
NO_3^--N	0.062	0.009	-0.031	0.461	-0.423	-0.383	-0.709*
TK	0.241	-0.164	-0.487	0.457	-0.441	-0.312	-0.234
AK	0.194	0.621*	-0.147	-0.814**	0.874***	0.315	0.245
TN	0.471	0.749**	-0.451	-0.596*	0.617*	-0.259	-0.269
TC	0.364	0.677*	-0.375	-0.730**	0.799**	0.132	0.053
pH	0.091	-0.050	-0.310	0.354	-0.390	0.236	-0.208
Ca	-0.100	-0.327	-0.207	0.082	-0.034	0.699*	0.447
Mg	0.560	0.427	-0.751**	-0.319	0.396	0.146	0.046

Table 4(on next page)

Loads and explained variances of 15 original variables in the first 4 principal components in principal component analysis (PCA)

Soil Physico-Chemical Properties	Principal Components			
	PC1	PC2	PC3	PC4
Soil electrical conductivity(EC)	-0.1388	0.0051	0.5871	0.3834
Soil water content (MC)	0.3282	-0.1627	0.0525	-0.0141
Soil bulk density(BD)	0.3717	-0.0857	0.1724	-0.1318
Total porosity of soil(TPO)	-0.3717	0.0857	-0.1725	0.1318
Soil available phosphorus (AP)	0.0319	0.4278	-0.0152	-0.248
Soil total phosphorus (TP)	0.1311	0.4082	0.1195	-0.156
Soil ammonium nitrogen(NH_4^+-N)	-0.1455	0.2207	-0.2497	0.4469
Soil nitrate nitrogen(NO_3^--N)	-0.194	0.0032	0.6078	0.1857
Soil total potassium (TK)	0.3541	-0.0017	0.2662	-0.1226
Soil available potassium (AK)	0.1063	0.3629	-0.1684	0.3398
Soil total nitrogen (TN)	0.1761	0.4272	0.0678	-0.093
Total soil carbon(TC)	0.3804	0.1608	-0.041	0.2386
Soil pH (pH)	0.0116	-0.3615	-0.1302	-0.1667
Ca	0.2464	-0.2976	-0.1155	0.4309
Mg	0.3827	-0.0353	-0.1053	0.2977
Eigenvalue	4.9399	4.2136	1.733	1.3464
Percentage of Variance (%)	32.93	28.09	11.55	8.98
Cumulative (%)	32.93	61.02	72.58	81.55

Figure 1

Soil physical properties under different soil layers and different agroforestry patterns

(A) changes of soil EC value (B) changes of soil MC; (C) changes of soil BD; (D) changes of soil TPO. There were significant differences in one-way ANOVA of different compound patterns with different letters (LSD, $P < 0.05$).

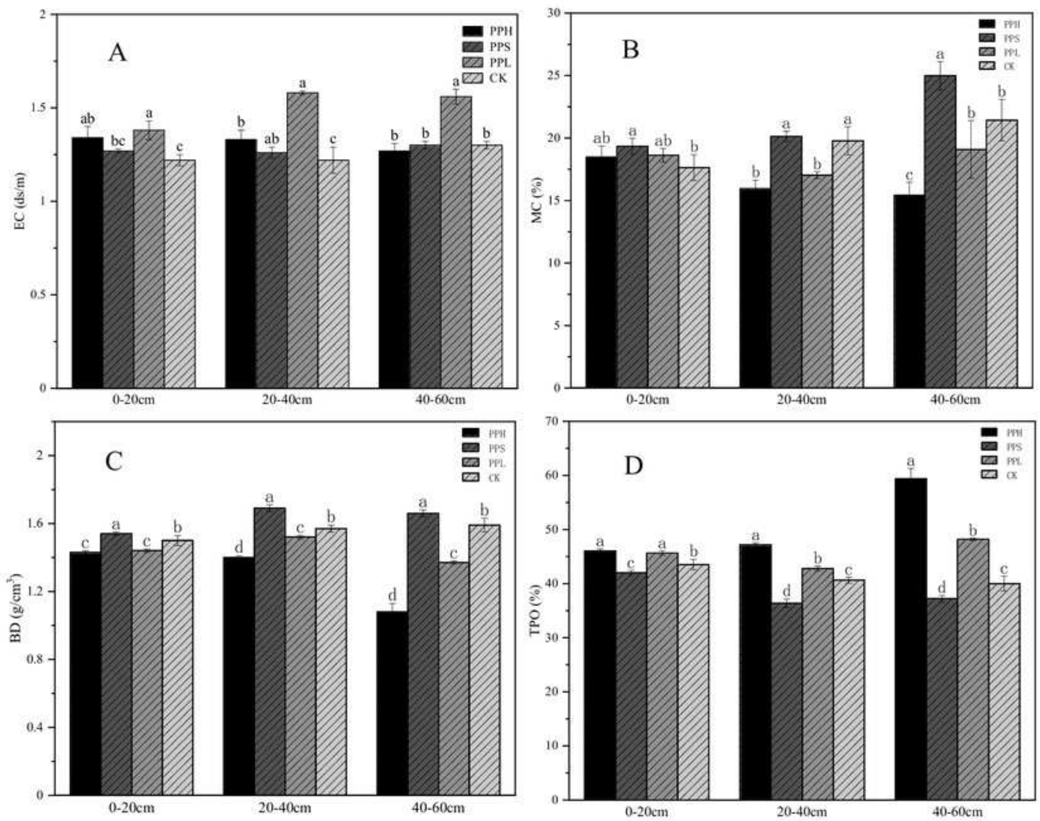

A
B
C
D
PPH
PPS
PPL
CK
EC (ds/m)
MC (%)
BD (g/cm3)
TPO (%)
0-20cm
20-40cm
40-60cm

Figure 2

Soil pH(A), Ca(B), Mg(C) in different soil layers under various agroforestry systems

The lowercase letters of different agroforestry systems in the same soil layer were different, and the difference was significant ($P < 0.05$).

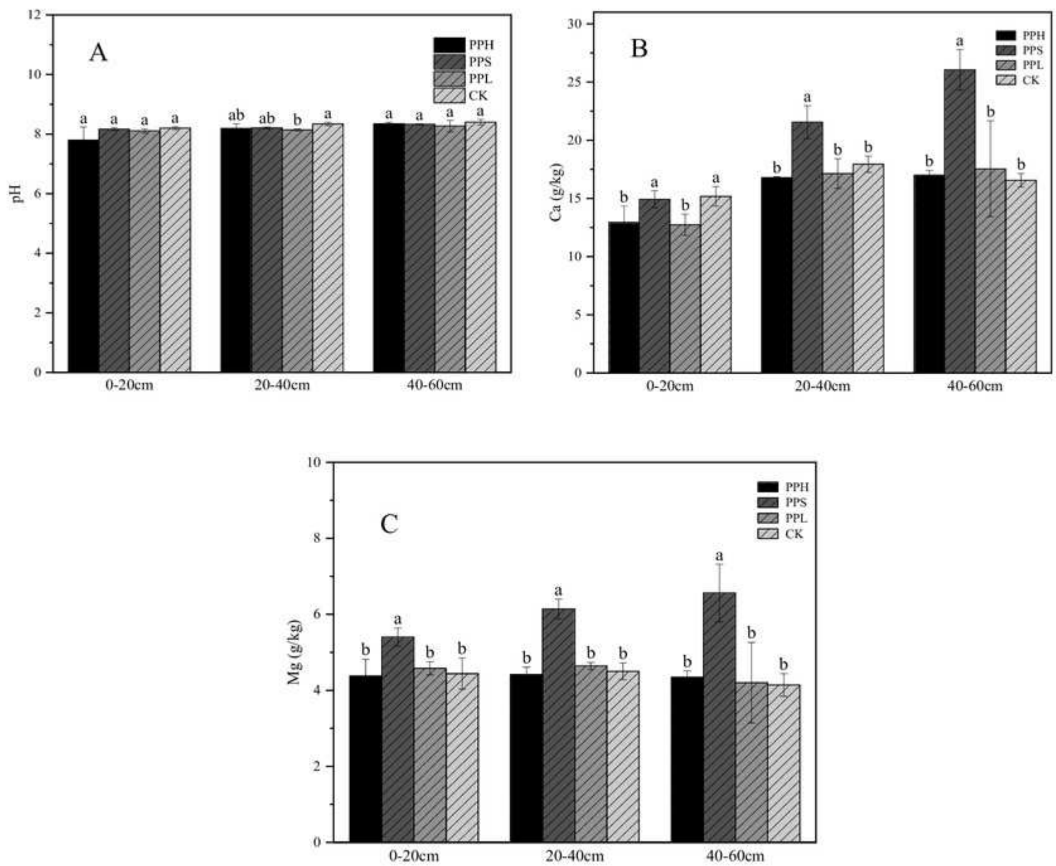

A
pH
PPH
PPS
PPL
CK
0-20cm
20-40cm
40-60cm
B
Ca (g/kg)
C
Mg (g/kg)

Figure 3

Correlation matrix between soil physical and chemical properties in different soil layers

Correlation matrix between physical and chemical properties of 0-20 cm soil (A); 20-40 cm correlation matrix between soil physical and chemical properties (B); 40-60 cm correlation matrix between soil physical and chemical properties (C).

S-UE, urease; S-AKP, alkalinephosphatase; S-PPO, polyphenoloxidase; S-CBH, cellobiohydrolase; S-NAG, 1,4-β-N-acetylglucosaminidase; S-POD, peroxidase; S-BG, β-1,4-glucosidase.

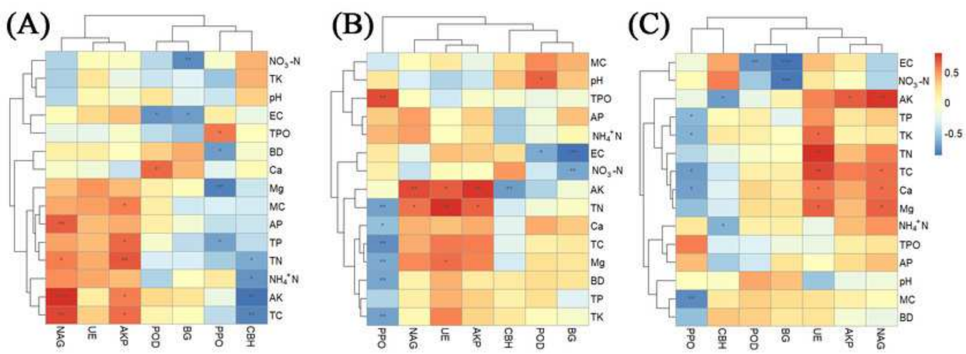
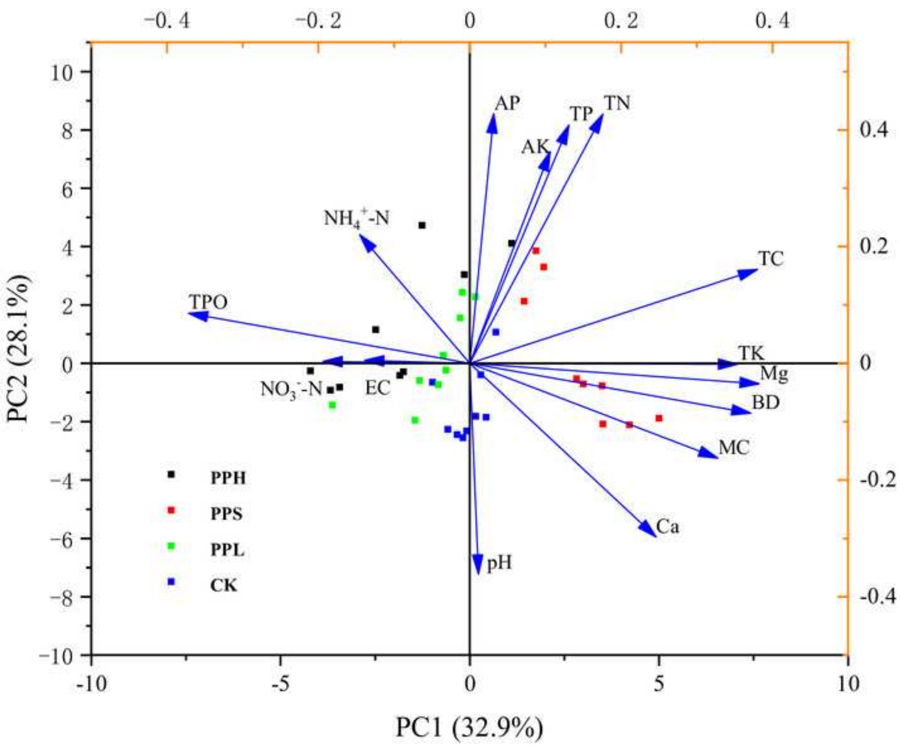

(A)
(B)
(C)

Figure 4

PCA ranking chart of soil physical and chemical properties of different pecan agroforestry models

Blue arrows indicate soil physical and chemical factors. Plots are represented by different color symbols. Specifically, black squares indicate PPH; red squares represent PPS; green squares represent PPL; blue squares represent CK. The abbreviations of soil physical and chemical properties are shown in Figure 2. There was a significant correlation between the angle of intersection and its corresponding variable, where an acute angle represents a positive correlation, an obtuse angle represents a negative correlation, and a right angle represents an insignificant correlation.


-0.4
-0.2
0
0.2
0.4
AP
TP
TN
AK
NH4+-N
TC
TPO
TK
Mg
BD
NO3--N
EC
MC
Ca
pH
PPH
PPS
PPL
CK
PC2 (28.1%)
PC1 (32.9%)
10
8
6
4
2
0
-2
-4
-6
-8
-10
-5
5
0.4
0.2
-0.2
-0.4