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Essay

Effects of Different Plantation Forest Types on Understory Herbs and Soil Properties in a Pisha Sandstone Area

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Abstract: Pisha sandstone areas are characterized by intense soil erosion and fragile ecological environment. Restoration efforts mainly focus on large-scale artificial planting of oil pine, sea buckthorn, and other trees and shrubs. To clarify the influence of different plantation forest types on the structure of understory herbaceous communities, species diversity, and soil physicochemical properties in pisha sandstone areas, and to determine suitable forest stands for soil and water conservation, this study provides a theoretical foundation for enhancing the ecological function of plantation forests in these regions. We investigated the relationships between three types of plantation forests and their understory herbaceous community composition, species diversity, and soil physicochemical properties through field sampling and laboratory experiments on the slopes of Xihedaigou in Jungar Banner. The study focused on pure Pinus sylvestris (YC) forests, mixed Pinus tabuliformis and Armeniaca sibirica (YS) forests, mixed Armeniaca sibirica and Amygdalus davidiana (SS) forests, and natural grassland (CK) as the research objects. (1) A total of 31 species of herbaceous plant species, belonging to nine families and 22 genera, were recorded in the understory of the three types of plantation forests in the study area. The dominant families were Gramineae, Compositae, Fabaceae, and Rosaceae. Among the forest types, YC had the highest number of species, followed by SS. Stand type had a significant effect on the species diversity of the understory herbaceous community (PSS>YS), with species diversity following the trend the highest YC, the second highest SS and the lowest YS. Moreover, the species diversity index, plant height, biomass, and total cover in the herbaceous layer were all highest in YC, followed by SS and YS. (2) Stand type had a remarkable effect on soil organic matter, quick-acting nitrogen, phosphorus, potassium (NPK), and soil water content in the understory ($P<0.05$). These soil properties varied by stand type, with values following the trend the highest YC, the second highest SS and the lowest YS. Notably, YS had significantly lower soil nutrients and water content than the other types of forests. (3) Principal component analysis showed that different forest stands ranked in the order of the highest YC, the second highest SS and the lowest YS based on combined scores of soil physicochemical properties and understory species diversity. This finding indicates that planting YC and SS is more conducive to promoting understory plant growth, increasing species diversity, and enhancing soil fertility.

Keywords*:* forest stand type; understory plant diversity; soil physicochemical properties; plantation forest; pisha sandstone area

Citation: To be added by editorial staff during production.

Academic Editor: Firstname Lastname

Received: date
Revised: date
Accepted: date
Published: date

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Soil serves as the fundamental substrate for plant survival [1], and the spatial distribution of soil nutrients affects the growth, biomass allocation, and overall structure of plant communities, including species composition, diversity, and the distribution of

above and below ground biomass [2]. In forest ecosystems, soil is essential for supporting tree growth and plays a key role in the recycling of materials and the energy flow. Soil physical and chemical properties are important components of forest soil ecosystems In nutrient cycling, solid nutrients are absorbed by plant roots, returned to the surface through litter, and released back into the soil via decomposition in the decomposer subsystem, completing the nutrient cycle within the ecosystem [3].The enrichment, spatial distribution, and redistribution of soil nutrients directly influence vegetation growth, development, and succession. Therefore, environmental factors, such as plant species and their distribution are closely related to soil nutrient dynamics [4]. Artificial afforestation is an important method for restoring forest ecosystems in arid and semi-arid regions with challenging natural conditions. Species diversity, which represents the diversification of plant communities at the species level, reflects the interactions between plant communities and their ecological environment [5]. Due to the monoculture nature of planted forest stands, species diversity is generally low. However, rational planting of suitable stands can enhance the community structure of these forests, increase species diversity, and improve soil nutrients in the understory [6]. The results of many studies have shown that different forest stand types exhibit remarkable effects on species diversity and soil nutrient content in planted forests,Pereira,A.P.A. et al. found that planting mixed forests was effective in increasing the C and N content of soil organic matter[7];Cherubin,M.R. et al. demonstrated that soil quality in mixed Eucalyptus forests is stronger than in pure Eucalyptus forests8];Sun,W.Y. showed that stand type can indirectly affect the distribution of understory plant diversity by regulating soil physicochemical properties[9].Therefore, the study of the influence mechanism of forest stand type on plant species diversity and soil physicochemical characteristics of planted forest land can provide an important theoretical reference for the rational planting of forest land and the sustainable management of soil and water conservation forests [10].

The pisha sandstone region covers an area of approximately 16,700 km^2, which is a concentrated source area of sediment in the upper and middle reaches of the Yellow River Basin because of its unique bedrock structure and low degree of diagenesis [11]. It is prone to outbreaks of highly sandy floods during the summer months when heavy rainfalls occur frequently [12]. Since the 1980s, national departments at all levels have carried out ecological restoration projects centered on planting artificial forests in pisha sandstone areas, such as Inner Mongolia and Shaanxi [13]. After decades of continuous attempts, the governance mode of vegetation configuration in the pisha sandstone area has become mature [14]. Trees, such as Pinus tabuliformis and Armeniaca sibirica, characterized by their resistance to drought, barrenness, and adaptability, are often planted on top of mountains and slopes in pisha sandstone regions, acting as soil and water conservation trees [15]. A field survey found that varying plantation forest stand types in the pisha sandstone region exhibit significant differences in tree understory herbaceous area, species diversity, and growth [16]. This study considers the plantation forests of three stand types on the slopes of Xihedaigou in Jungarqi Banner as the research object. Moreover, the differences among plant community composition, species diversity index, and soil physicochemical properties under varying stands are analyzed through field surveys and indoor experiments. This approach aims to explore the interrelationships between stand types and understory species diversity and soil physicochemical properties, as well as to determine suitable soil and water conservation stand types, providing a reference for the enhancement of ecological functions and sustainable development of plantation forests in the pisha sandstone area [17].

1. Materials and methods

1.1. Overview of the study area

The study area is located in the West Heidaigou watershed of Xuejiawan Town, Jungar Banner, Ordos City, Inner Mongolia, where bedrock is exposed over a large area. The exposed area accounts for more than 70% of the total area, covered by loess at a depth of 40–60 cm, and underlain by pisha sandstone [18]. The soil type is dominated by calcareous chestnut soils. The geomorphology consists mostly of granular hills with gullies and ravines, with altitudes ranging from 1110 m to 1300 m. The region has a temperate continental climate, with long dry winters and short warm summers [19]. Rainfall is concentrated in the summer months of June to August, with torrential rains dominating the rainfall, and an annual total of approximately 400 mm [20]. The natural vegetation in the study area is not well preserved, characterized by low species diversity and sparse cover [21]. The herbaceous vegetation is mainly composed of big needle fescue (*Stipa grandis*) and thyme (*Thymus mongolicus*). Shrubs are mainly sea buckthorn (*Hippophae rhamnoides*), lemon bar (*Caragana korshinskii*), and caraway (*Lespedeza bicolor*). The primary tree species is the creosote bush (*Pinus tabuliformis*) [22].

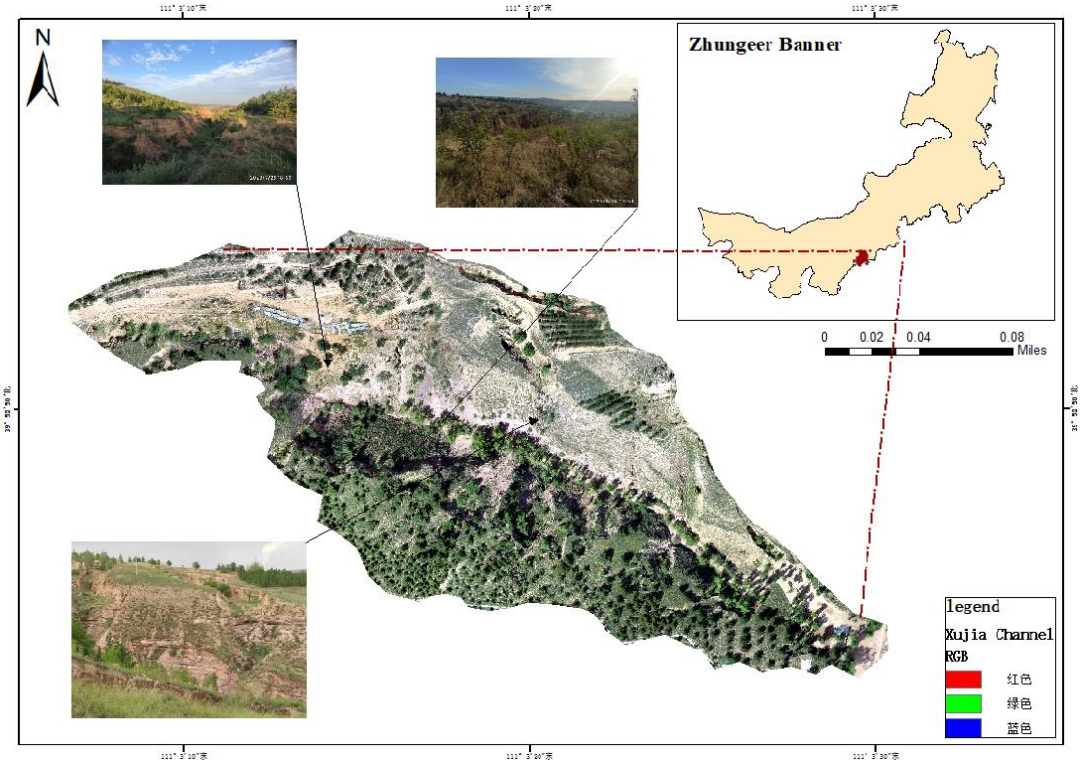

Figure 1. Map of the study area.

1.2. Research methodology

1.2.1. Field Sample Plot Layout and Vegetation Survey

In August 2023, in the upper reaches of Xihedaigou in Jungarqi county, well-grown of YC,YS,SS andCK(control groups) with essentially the same stand structure were used for the study. A number of tree sample plots with basically the same density, slope, slope direction, and elevation were selected for each forest stand, and three tree sample plots of 20m×20m were evenly distributed. The method of checking feet per tree [23] was used to investigate and record the diameter at breast height (DBH), tree height, number of plants, and crown width of trees in the sample plots. Moreover, three 1m×1m herbaceous sample plots were set up to record the names, numbers, heights, and cover degrees of shrubs and herbaceous plants.

Table 1. Basic information of sample plots.

Sample size	Stand type	Elevation/m	Slope direction	Slope/°	Density /(plant-hm^{-2})	Chest diameter/cm	Average tree height/m	Age/a
1	YC	1208	Sunny slope	15	3200	44.63	5.24	16
2		1223		15		38.55	4.83	
3		1216		14		42.08	4.52	
4	YS	1205	Semi-permanent slope	16	3250	41.84	3.75	15
5		1211		15		44.39	4.23	
6	SS	1204	Sunny slope	16	3150	37.75	3.98	13
7		1203		15		39.38	4.42	
8		1209	Semi-permanent slope	15		36.15	5.10	
9		1213		16		34.38	4.52	
10	CK	1185	Sunny slope	15	—	—	—	—
11		1187		15				
12		1193		16				

1.2.2. Measurement of aboveground biomass of herbs

The aboveground parts of the plants in the herb sample plots were harvested by mowing method, placed into kraft paper bags, and their fresh weights were determined. Then, the samples were brought back indoors and dried in an oven at 75 °C until constant weight; their dry weights and the aboveground biomass of the herbs were calculated.

1.2.3. Species diversity calculations

The species composition, cover, height, and biomass of the vegetation in the herbaceous samples were determined to derive the relative cover (RC), relative height (RH), and relative biomass (RS) of the plants in the samples. Finally, the importance value (IV) of the species in the samples was calculated. Four indices, namely, Shannon–Wiener diversity index (H), Simpson's dominance index (D), Margalef's richness index (R), and Pielou's uniformity (Jsw) index were used to analyze the diversity of vegetation in this sample site. The calculation formulas are as follows [24]:

(IV):

$$IV = \frac{Rc + Rh + Rs}{3} \quad (1)$$

$$Rc = \frac{\text{Coverage of species}}{\text{Sum of cover of all species}} \times 100\% \quad (2)$$

$$Rh = \frac{\text{Height of species}}{\text{Sum of heights of all species}} \times 100\% \quad (3)$$

$$Rs = \frac{\text{Biomass of species}}{\text{Sum of biomass of all species}} \times 100\% \quad (4)$$

Shannon-Wiener:

$$H' = -\sum P_i \ln P_i \quad (5)$$

Simpson:

$$D = 1 - \sum P_i^2 \quad (6)$$

Pielou:

$$J_w = \frac{H'}{\ln S} \quad (7)$$

Margalef:

$$R = \frac{S - 1}{\ln N} \quad (8)$$

where Rc, Rh, and Rs represent relative cover, relative height, and relative biomass, respectively; *S* indicates the total number of species in the sample; Pi refers to the relative number of individuals of the *i*th species (i.e., number of individuals/total number of species: Ni/N); *N* denotes the total number of individuals of all the species in the sample, and Ni depicts the number of individuals of the *i*th species.

1.2.4. Determination of soil physical and chemical properties

The nutrients and water that plants can draw are mainly concentrated in the 0–40 cm soil layer because of the shallow loess overburden and buried pisha sandstone in the study area. Thus, the experiment was conducted in each tree sample plot by randomly digging three soil profiles at a depth of 40 cm, and soil samples were collected at four depths, namely, 0–10, 10–20, 20–30, and 30–40 cm, by using a ring knife and a soil shovel. Then, they were brought back to the room for analysis. Soil moisture content and bulk weight were determined by drying method, and soil particle size was determined by Malvern 3000 laser particle size diffractometer. Soil organic matter was determined by heating and oxidation with potassium dichromate, fast-acting phosphorus by molybdenum antimony colorimetric method with sodium bicarbonate immersion, fast-acting potassium by flame photometric method with ammonia acetate immersion, and alkaline dissolved nitrogen by alkaline dissolved diffusion method.

1.2.5. Data processing

Excel2019 and SPSS26.0 software were used for statistical organization and analysis of data and Origin2021 for graphing. SPSS26.0 software was used for one-way ANOVA, least significant difference (LSD) method was employed to test the differences on each characteristic index under different silvicultural densities, Pearson correlation coefficient

was applied to carry out the data correlation analysis, and Canoco5 was utilized for data principal component analysis.

2. Results and analysis

2.1. Characteristics of understory vegetation in different forest stands

2.1.1. Characterization of plant community composition and important values

The herbaceous layer under plantation forests, and among these plants present 31 species of plants in nine families and 22 genera. Eight species of Gramineae, nine species of Asteraceae, five species of Leguminosae, and three species of Rosaceae accounted for 25.81%, 29.03%, 16.13%, and 9.68% of the total number of species, respectively. The trend of the number of species in the herbaceous layer with stand type was YC>SS>YS>CK, and the difference between their upper and lower peaks was 7.

Table 2. Species composition of herbaceous plant communities under different forest densities.

Stand type	Family	Genus	Species
YC	7	14	17
YS	6	12	14
SS	7	13	15
CK	5	8	10

As shown in Table 3, the main dominant species in the herbaceous layer under the plantation forest were the adaptable, drought-resistant, alkali-resistant, and barren-tolerant big needlegrass, Benjamin's needlegrass, goat grass, brown cryptomeria, and huckleberry. In YC, the establishment species was big needle fescue, and the dominant species were Artemisia oxalis, Artemisia ferruginea, and other temperature and humidity-loving plants. In SS big needle fescue, the importance value (73.0) was greater than that of YC (43.0), and the dominant species, such as Thymus, Commiphora bifidus, and Astragalus stramonium, appeared. In YS and CK, the established species is Benjamin's needlegrass, and the dominant species are common species in the pisha sandstone area, such as big needlegrass, short-flowered needlegrass, and goatgrass. Thus, YC and SS remarkably affect the understory species diversity.

Table 3. Important values of understory herbaceous plants under different densities.

Stage	Stand type	Main species and importance values (%)
Herbaceous layer	YC	(Stipa-grandis43.0)+Artemisia-gmelinii(24.0)+Artemisia-dubia(24.0)+Leymus-chinensis(22.0)+Potentilla-tanacetifolia(11.0)
	YS	Stipa-capillata(44.0)+Stipa-grandis(29.0)+Stipa-breviflora(28.0)+Leymus-chinensis(16.0)+Lespedeza-bicolor(15.0)
	SS	Stipa-grandis(73.0)+Thymus-mongolicus(63.0)+Leymus-chinensis(30.0)+Aster-altaicus(12.0)+Lespedeza-bicolor(11.0)

CK	Stipa-capillata(48.0)+Stipa-grandis(34.0)+Leymus-chinensis(25.0)+Stipa-breviflora(25.0)+Lespedeza-bicolor(17.0)

Note: Only the understory herbaceous plants with the five top important values are listed in the table.

2.1.2. Plant community growth characteristics

Table 4 shows that the different types of forest stands exhibited significant effects on the growth characteristics of understory herbs (P<0.05), and the average plant height in the understory herb layer showed CK>YC>YS>SS, depending on the stand type. The total cover showed YC>CK>YS>SS, and the total biomass exhibited CK>YC>SS>YS. Evidently, the YC forests demonstrated the best growth and development of the understory herbaceous vegetation.

Table 4. Growth characteristics of understory herbaceous plants under different densities in pine forest.

Stand type	Total cover/%	Total biomass/gm^3	Average height/cm
YC	38.61±4.63a	193.21±61.21a	25.05±5.34ab
YS	17.27±5.32b	149.33±28.89c	23.73±5.21b
SS	19.22±7.75b	180.41±57.91b	24.01±2.29b
CK	16.57±4.08b	194.31±8.85a	28.27±9.14a

Note: Different lowercase letters in the table indicate significant differences (P < 0.05).

2.1.3. Characterization of plant community species diversity

As shown in Figure 2, the four species diversity indices differed significantly (P<0.05) among varying stand types. With different stand types, Shannon–Wiener index, Pielou index, and Margalef index showed

YC>SS>YS>CK, and Simpson index presented CK>SS>YC>YS.

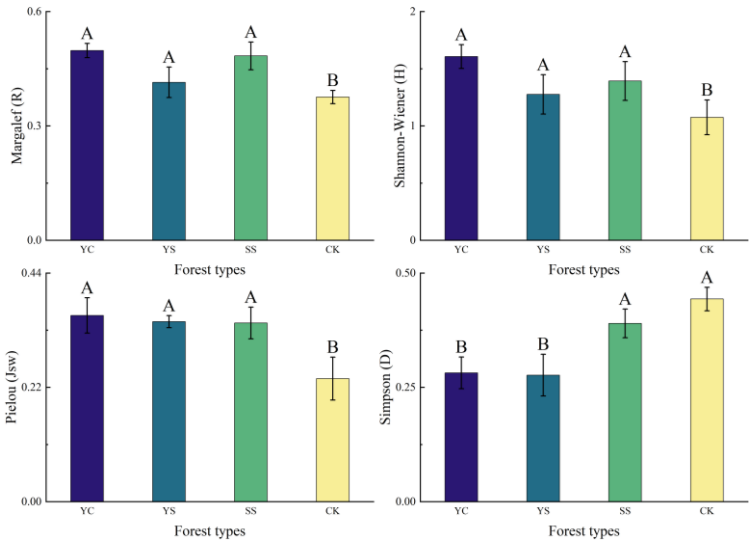

Figure 2. Characteristics of species diversity index of understory herb layer plant community in Pinus tabulaeformis forest.

Note: Different capital letters in the figure indicate significant differences ($P< 0.05$).

2.2. Characteristics of soil physicochemical properties in the understory of different forest stands

2.2.1. Soil physical properties

Figure 3 shows that the forest stand type demonstrated a significant ($P<0.05$) effect on soil bulk weight and soil water content in the 0–40 cm soil layer, and soil bulk weight varied with forest stand as YC>YS>SS>CK. Soil water content varied with forest stand as YC>SS>YS>CK, showing that YC improved water holding and texture of under story soil better than the other forest stands.

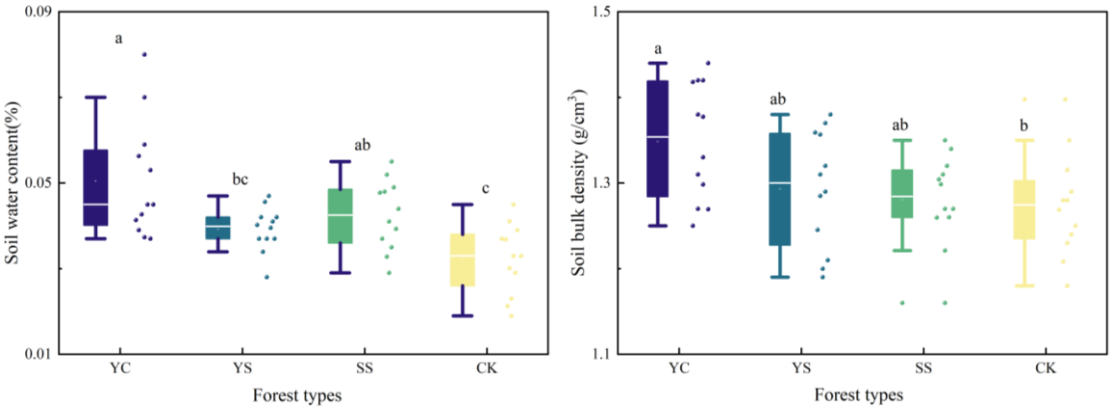

Figure 3. Characteristics of 0–40 cm soil water content and soil bulk weight under different forest stands.

Note: Different lowercase letters indicated significant differences between varying stand densities in the same soil layer ($P < 0.05$).

2.2.2. Soil chemical properties

Figures 4 and 5 illustrate that differences in forest stand considerably affect ($P<0.05$) the soil alkaline nitrogen, effective phosphorus, quick-acting potassium, and organic matter content. In general, these soil nutrients decreased with the increase in soil depth, and mainly gathered in the 0–20 cm soil layer. Organic matter, alkaline dissolved nitrogen (ADN), effective phosphorus (EP), and quick-acting potassium (QAP) contents varied with forest stand in the form of YC>SS>CK>YS.

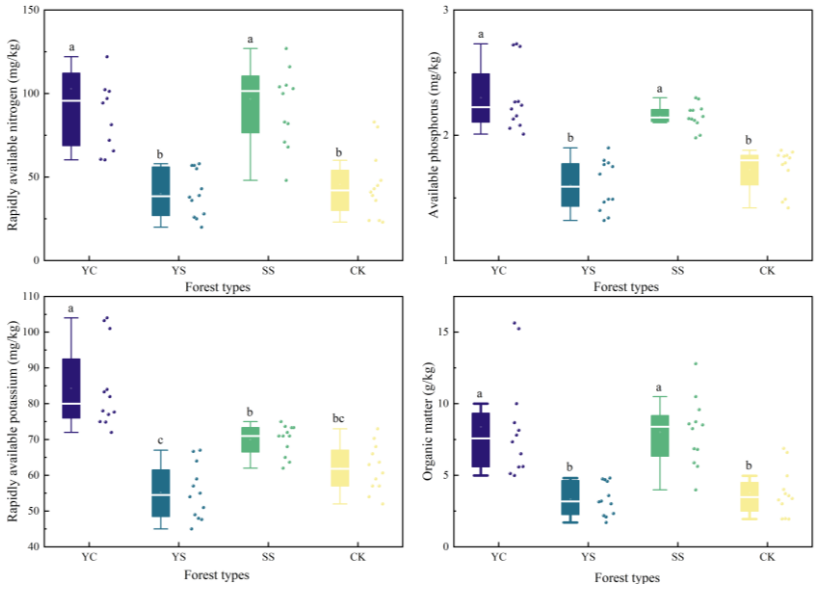

Figure 4. Characteristics of soil available N, P, K, and organic matter under different forest stands.

Note: Different lowercase letters indicate significant differences between varying stands ($P < 0.05$)

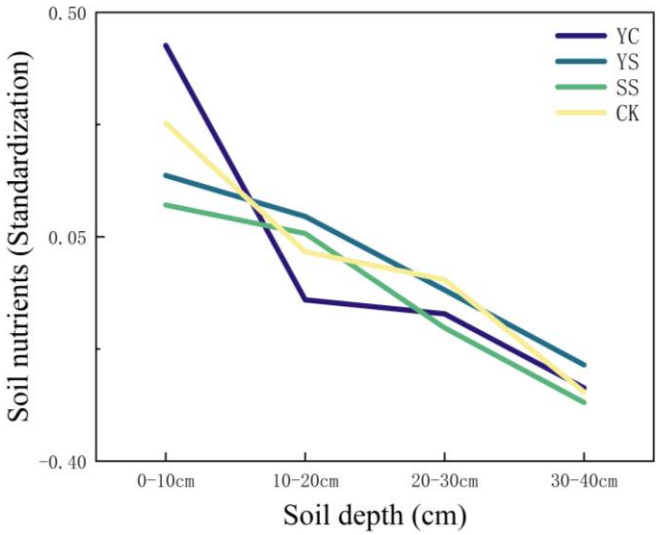

Figure 5. Normalized trend of soil nutrients from 0–40 cm in different forest stands.

2. 3. Principal component analysis of understory plant diversity and soil factors

Prior to the PCA,In order to assess the correlation between the indicators,KMO and Bartlett sphericity tests were required.As shown in table 5,A KMO value greater than 0.6 indicates a high correlation between the indicators and is considered acceptable.A p-value of less than 0.00 in the Bartlett's test of sphericity indicates that there is a correlation between the indicators and that they are suitable for factor analysis.

Table 5. KMO and Bartlett's test.

KMO Sampling appropriateness quantity		0.64
Bartlett's Test of Sphericity	Chi-square approximations	1046.848
	Degree of freedom	78
	Significance	0.00

The principal component analysis of the measured plant diversity indicators and soil physical and chemical properties of each forest stand demonstrated a contribution rate of 50.13%, that of principal component 2 was 21.57%, and that of principal component 3 was 9.54%. Furthermore, the cumulative contribution rate of these principal components amounted to 81.24%, which basically reflected the vast majority of the information of the 13 selected indicators (Table 6).

Table 6. Correlation between understory plant diversity index and soil physical and chemical properties of the Pinus tabulaeformis Forest.

Indicator name	Principal component		
	1	2	3
Organic matter	0.829	0.224	−0.414
Alkaline hydrolysis of nitrogen	0.835	0.223	−0.408
Effective phosphorus	0.88	0.261	−0.255
Quick-acting potassium	0.86	0.322	−0.135
Soil capacity	0.474	−0.036	0.592
Soil moisture content	0.624	−0.106	0.297
Margalef	0.882	−0.172	−0.024
Simpson	−0.361	0.794	−0.117
Pielou	0.667	−0.618	0.03
Shannon–Wiener	0.917	−0.153	0.215
Biocapacity	0.8	0.045	0.393
Biomass	0.368	0.859	0.196
Plant height	−0.186	0.845	0.356
Eigenvalue (math.)	6.517	2.804	1.24
Contribution rate	50.132	21.567	9.536
Cumulative contribution	50.132	71.699	81.235

The weights of the three main components were calculated using the factor loading values and criterion variables. Then, the composite scores of each stand type were calculated using the eigenvalues. These scores were normalized to obtain the composite scores of the different stand types using understory plant diversity and soil physicochemical properties (Table 6).

Table 6. Composite scores and ranking of different stand types.

Stand type	F_1	F_2	F_3	Aggregate score	Comprehensive Ranking
YC	3.37	0.05	0.75	1.77	1
YS	0.89	0.09	−1.13	0.36	2
SS	−1.66	−2.31	0.07	−1.33	4
CK	−2.60	2.17	0.31	−0.81	3

Table 6 illustrates that the comprehensive ranking of different stand types is YC>SS>CK>YS, indicating that the species diversity and soil physicochemical properties in YC and SS are better than those of other stand densities. Moreover, YC is more conducive to the role of soil and water conservation in plantation woodlands in the pisha sandstone area than the other stand types.

3. Discussion

3. 1. Effects of stand type on species composition, species diversity, and growth characteristics of herbaceous plants under plantation forests

In forest ecosystems, understory vegetation plays an important role in maintaining biodiversity and ecosystem function[25].The Species Diversity Index (SDI) is a measure of the diversity of species within a community and an indicator of the stability of a community or ecosystem [26];Mean plant height, cover, and aboveground biomass had a significant effect on the conservation of soil and water[27],In contrast, stand type had a significant effect on understory vegetation diversity, growth characteristics and biomass[28].In recent years, China has planted large areas of soil and water conservation trees in pisha sandstone areas [29],The continuous reduction of degraded grassland and bedrock exposure and the gradual increase in the amount of understorey vegetation [30],but there have been fewer studies on the diversity and growth characteristics of understory plants.Therefore,this study quantified plant species diversity and growth characteristics in the understory of different plantation forests,These parameters can provide valuable insights into the rational planting of plantation forests.

A total of 31 species in nine families and 22 genera of plants were found in the herbaceous layer of the plantation forest understory in this study, and the barren-tolerant grasses, Asteraceae, and legumes dominated the community succession. With different stand types, the number of herbaceous community species showed YCmax, SS second, CK minimum,The results were similar to those of Yang,Y.F. et al. on lateral cypress plantations in Renshou Mountain, Lanzhou, China[31].Difference in stand types caused interspecific competition among varying tree species in the understory [32]. As a result, the understory light, hydrothermal conditions, and nutrient content and distribution in the soil vary 33]. Such differences remarkably affect the species and distribution of plants in their understory [34]. In YC, temperature- and humidity-loving plants, such as Artemisia cattail and Artemisia ferruginea, appeared as dominant species [35], and dominant species, such as Thymus vulgaris and Commiphora dioica, were evident in SS. The dominant species in YS and CK were common, including big needlegrass, short-flowered needlegrass, and goatgrass. This finding indicates that the light and hydrothermal strips, as well as the nutrient content of soil in the understory of YC and SS were significantly superior to those of YS and CK.Additionally,stand type also significantly affected (P<0.05) the species diversity of understory herbaceous communities. With different stand types, Shannon–Wiener index, Pielou index, and Margalef index showed YCmax, SS second, CK minimum.Most of the studies such as Hu, L.D. et al. concluded that mixed forests have higher species diversity than pure forests,[36]which is contrary to the findings of the present study.The reason for this may be that as a native tree of the pisha sandstone area,In the short term, pinus forest are better adapted to the harsh local environment than other forest stands，resulting in a higher plant diversity in YC than in YS and SS.Whether the results of this study vary over longer time scales remains to be seen.In this study,the stand type had a significant (P<0.05) effect on aboveground biomass of understory herbaceous plants, mean plant height, and total cover. The result demonstrated that the total plant cover was the highest in YC forest and the lowest in CK. The average plant height was at the peak in CK and the lowest value in YS,The aboveground biomass showed CK (194.31) ,YC (193.21), SS (180.41),YS (149.33),This is similar to the findings of Wang,L.et al[37].The reasons for this may be the limited soil moisture and nutrients in CK,The Group species dominate the competition for resources[38],Resulting in low species diversity and low community cover.YS aboveground biomass is much lower than other stands, which shows that soil moisture and nutrients are at a low level in this stand[39].

3. 2. Influence of forest stand type on the physicochemical properties of soil under plantation forests

The physical properties of soil directly or indirectly affect the growth and development of forest trees by controlling water supply, gas exchange, and root uptake in the

underground part of the plant [40]. In this study, stand type significantly (P<0.05) affected soil bulk weight and soil water content,Špulák, O. et al[41]. also proved that the type of forest stand has a significant effect on soil bulk weight and water contentThe soil bulk weight of YC and SS increased slightly with the deepening of the soil layer, whereas that of YS and CK did not change considerably with the deepening of the soil layer. The water content of the surface soil was greater than that of the deep soil in YC and SS, whereas the result was opposite in YS and CK [42]. The soil bulk weight and water content of YC and SS were better than those of the other stands in terms of the different forest types. This finding suggests that YC and SS are more favorable to the improvement of soil structure and maintenance of soil moisture in the oil pine woodland in the pisha sandstone area, and can better play the role of soil and water conservation [43].

Differences in stand types of planted forest lands lead to variation in their understory light and hydrothermal conditions, understory plant community structure, and understory litter species [44]. Differences in these factors influence the chemical properties of understory soils [45]. This finding indicates that stand type had a significant effect (P<0.05) on soil alkaline nitrogen, effective phosphorus, quick-acting potassium, and organic matter content [46]. Overall, soil nutrients decreased with increasing soil depth, mainly clustered in the 0–20 cm soil layer,Similar conclusions were reached by Dong, L.J. et al[47]. Organic matter, alkaline dissolved nitrogen, effective phosphorus, and quick-acting potassium content varied with stand, showing YCmax, SS second, YS minimum, with SS being approximately 8.3% lower in soil nutrient content than YC, and YS decreasing by approximately 39.3% in soil nutrient content than YC. The two reasons for this finding are as follows: first, intense interspecific competition exists between the oil pine and mountain almond for understory water or certain types of nutrients [48], leading to a shortage in this resource in the understory after consuming a large amount of soil water or nutrients. This condition seriously affects the growth and development of other species in the understory. Second, the planting density of this mixed forest is extremely large, intensifying the competition for understory soil water and nutrients [49], leading to a decline in soil fertility of this forest stand.

3. 3. Influence of stand type on management of planted woodlands

PCA is a technique for simplifying datasets, Commonly used to reduce the dimensionality of a dataset and converting multiple indicators into a few composite indicators,while maintaining the characteristics of the dataset that contribute the most to variance[50].PCA is widely used in various fields,The principal component analysis (SD-PCA) model was introduced by Liujw et al,Investigating heavy metal contamination of soils in urban areas of northwestern China,Agriculture, transportation, and natural sources were found to contribute 65.5%, 17.9%, and 11.1%, respectively[51].Yang.Z.H et al bewerteten und untersuchten erfolgreich Pilze mit verschiedenen bioaktiven Eigenschaften mittels PCA,Diese analyse liefert einen Datensatz für den Vergleich und die Auswahl mehrerer bioaktiver Pilze[52].This study uses principal component analysis,After standardization of understory species diversity, soil nutrients and other parameters,the comprehensive scores of each stand were calculated,Visual comparisons can be made of the advantages and disadvantages of vegetation growth and development, soil nutrients and structure among different stands,and the stand types with good soil and water conservation function in Pisha sandstone area can be obtained.

The results of PCA indicates that YC was higher than other forest stands in the composite scores of soil physicochemical properties and understory species diversity analysis. SS was the second highest, and YS had the lowest composite score. This finding shows that plantation forest stand type had a significant effect on understory soil physicochemical properties and vegetation condition,the results of this study are in agreement with those of Wang,N. et al[53]. The SS trees are two to three years younger than those of other stands, and if the age of the trees is the same, then the soil and water conservation function of this stand cannot be enhanced [54]. Significant interspecific competition may exist

among the tree species in YS, or the planting density may be overly high for this stand type, exacerbating understory water and nutrient depredation by both species [55]. This condition results in significantly low understory soil physicochemical properties and understory species diversity [56]. This study conveys that, to realize ecological management in the pisha sandstone area and maintain soil nutrients and moisture at a high level, YC or SS is recommended with planting density of approximately 3250 plants/hm^2 for erosion control and protection of the local ecological environment [57]. Planting YS with a density of approximately 3250 plants/hm^2 is recommended, The condition of low soil nutrients, moisture and species diversity in this forest stand should be followed up continuously to provide a theoretical basis for the rational planting of soil and water conservation forest stands in the region[58].

4. Conclusions

In this study, three types of plantation forests in the pisha Sandstone District were studied，analyzed the diversity of understory herbaceous species, soil physicochemical characteristics of three plantation forests in the pisha sandstone area, and calculated the composite scores of different forest stands using principal component analysis.It was found that a total of 31 herbaceous plant species from 9 families and 22 genera occurred in the three plantation forests investigated, dominated by Gramineae, Asteraceae, and Leguminosae, with the highest number of plant species in YC and the second highest in SS.Stand type significantly ($P<0.05$) affected species diversity, soil organic matter, quick-acting nitrogen, phosphorus and potassium, and soil water content of the understory herbaceous community,Species diversity indices, growth characteristics and soil physicochemical characteristics of the herbaceous layer varied with stand types, with YC being the highest, SS the second highest and YS the lowest, and YS being significantly lower in soil nutrient and water content compared with other stand types.In the PCA, different stand types showed the highest YC, the second highest SS and the lowest YS in the combined scores of soil physical and chemical properties and understory species diversity analysis.Studies have shown that YC and SS are more conducive to understory plant growth, species diversity and soil fertility improvement than YS.In the future, the region should focus on researching the influence of plantation types and densities on their ability to conserve soil and water, determining scientific and reasonable plantation types and plantation densities, and realizing the rational management and sustainable development of soil and water conservation forest stands.In view of the significantly low soil nutrients, water and species diversity of YS, research should be carried out according to its planting density, site conditions, etc., so as to clarify the mechanism of soil nutrient and water utilization of this mixed forest, and thus better play its role of soil and water conservation in the pisha sandstone area.

Supplementary Materials:Author Contributions: D.F.: Conceptualization, Formal analysis, Investigation, Methodology, Supervision, Visualization, Writing—original draft, Writing—review and editing. Z.Y.: Investigation, Writing—original draft. J.G.:Data curation, Formal analysis,Investigation, Methodology, Visualization, Writing—original draft. F.Q.: Formal analysis, Investigation, Methodology, Visualization, Writing—original draft. H.H.: Writing—review and editing. W.H.: Writing—review and editing. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by the Open project of Key Laboratory of Soil and Water Conservation on Loess Plateau, Ministry of Water Resources(WSCLP202302) ,Ordos City Water Science and Technology Plan Project "The evaluation of the integrated benefits of soil and water conservation technology in key areas prone to soil and water loss in Xihedai Basin for ecosystem improvement", Inner Mongolia Autonomous Region "Science and Technology to Prosper Mongolia" Action Key Project (2022EEDSKJXM003),National Key Research and Development Program of China (No. 2023YFF1305104), National Natural Science Foundation project(42307463).

Data Availability Statement: The original contributions presented in this study are included in the Supplementary Materials; further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as potential conflicts of interest.

References:

1. Gao,J.;Wang,J.F.;Li,Y.H.Effects of Soil Nutrients on Plant Nutrient Traits in Natural Pinus tabuliformis Forests.Plants.2023,12,735-735.https://doi.org/10.3390/plants12040735.
2. Wang,H.C.;He,X.H.;Zhang,Y.J.;Xiao,J.L.;Wang,H.;Ma,M.G.;Ryunosuke,T.;Shi,W.Y.Variations in litter-soil properties between planted and naturally restored forests drive microbial community structure and function.Applied Soil Ecology.2023,189,104977-104977.https://doi.org/10.1016/j.apsoil.2023.104977.
3. Rubio,J.P.;Perea,A.J.;Garrido,J.L.H.;Alcántara,J.M.;Aguilar,C.A.;García,Á.L.;Rincón,A.M.Plant Traits and Phylogeny Predict Soil Carbon and Nutrient Cycling in Mediterranean Mixed Forests.Ecosystems.2023,26,1047-1060.https://doi.org/10.1007/s10021-022-00815-z.
4. Dietterich,L.H.;Bouskill,L.N.;Brown,M.;Castro,B.;Chacon.S.S.;Colburn,L.;Cordeiro,A.L.Effects of experimental and seasonal drying on soil microbial biomass and nutrient cycling in four lowland tropical forests.Biogeochemistry.2022,161,227-250.https://doi.org/10.1007/s10533-022-00980-2.
5. Song,S.K.;Yang,R.;Cui,X.R.;Chen,Q.County-Scale Spatial Distribution of Soil Nutrients and Driving Factors in Semiarid Loess Plateau Farmland.China. Agronomy.2023,13,2589-2589.https://doi.org/10.3390/agronomy13102589.
6. Boz,G.;Maryo,M.Woody Species Diversity and Vegetation Structure of Wurg Forest, Southwest Ethiopia.International Journal of Forestry Research.2020,1,17.https://doi.org/10.1155/2020/8823990.
7. Pereira,A.P.A.;Santana,M.C.;Zagatto,M.R.G.;Brandani,C.B.;Wang,J.T.;Verma,J.P.;Singh,B.K.Nitrogen-fixing trees in mixed forest systems regulate the ecology of fungal community and phosphorus cycling.Science of The Total Environment.2021,758,143711-143711.https://doi.org/10.1016/j.scitotenv.2020.143711.
8. Pereira,A.P.A.l;Cherubin,M.R.;Araújo,A.S.F.;Santana,M.C.;Medeiros,I.V.;Costa,D.P.;Souza,A.J.Soil Quality Evaluation in Mono and Mixed Eucalypt Plantation.Sustainability.2024,16,2534-2534.https://doi.org/10.3390/su16062534.
9. Sun,W.Y.;Yu,X.X;Jia,G.D.Correlation Between Soil Factors and Understory Plant Diversity in Different Plantations in Semi-Arid Regions of Lnner Mongolia.Journal of Northeast Forestry University.2024,52:51-57.DOI:10.13759/j.cnki.dlxb.2024.07.011.
10. Zhou,Y.;Liu,C.H.;Ai,N.;Qin,J.F.;Shi,J.H.;Nan,Z.Z..Soil fauna community characteristics and driving factors of Pinus tabuliformis in the loess region of northern Shaanxi.Catena.2023,229,107196-107196.https://doi.org/10.1016/j.catena.2023.107196.
11. Guo,J.J.;Shi,Y.H.;Wu,L.H.Gravity erosion and lithology in Pisha sandstone in southern Inner Mongolia.Journal of Groundwater Science and Engineering.2015,3,45-58.https://doi.org/10.26599/jgse.2015.9280007.
12. Xie,F.B.;Zhao,G.J.;Mu,X.M.;Tian,P.;Gao,P.;Sun,W.Y.Sediment Yield in Dam-Controlled Watersheds in the Pisha Sandstone Region on the Northern Loess Plateau.China.Land.2021,10,1264-1264.https://doi.org/10.3390/land10111264.
13. Shen,Z.Z.;Yao,W.;Xiao,P.Q.;Wu,Y.;Song,J.G.;Liu,J.;Liu,M.X.Research Progress of Soil and Water Conservation in Pisha Stone Area of Yellow River.Journal of Physics:Conference Series.2020,1637,012085-012085.https://doi.org/10.1088/1742-6596/1637/1/012085.
14. Wang,R.J.;Yan,F.;Wang,Y.J.Vegetation Growth Status and Topographic Effects in the Pisha Sandstone Area of China.Remote Sensing.2020,12,2759-2759.https://doi.org/10.3390/rs12172759.
15. Zhu,Z.L.;Li,L.;Zhang,S.X.;Zhang,P.;Ren,Y.;Yu,Z.G.Dynamic simulation study of soil erosion intensity on slopes with different vegetation patterns in pisha sandstone area.Ecological Modelling.2024,491,110665-110665.https://doi.org/10.1016/j.ecolmodel.2024.110665.
16. Xiao,P.Q.;Yao,W.;Pan,Z.Y.;Yang,C.Research on the Technologyof Anti-Erosion and Vegetation Promotion for Pisha Sandstone Region in the Middle Yellow River Basin.null.2020,0,0-0.https://doi.org/10.5194/egusphere-egu2020-3990.
17. Xiao,P.;Yang,C.;Jing,C.Research progress and harnessing method of soil and water loss in Pisha Sandstone region.IOP Conference Series: Earth and Environmental Science.2018,15,062084-062084.https://doi.org/10.1088/1755-1315/153/6/062084.
18. Zhao,G.J.;,Mu,X.M.;Han,M.W.;An,Z.G.;Gao,P.;Sun,W.Y.;Xu,W.Sediment yield and sources in dam-controlled watersheds on the northern Loess Plateau.Catena.2017,149,110-119.https://doi.org/10.1016/j.catena.2016.09.010.
19. Yang,C.X.;Zhen,B.B.;Xiao,P.Q.;Zhang,P.Study on the Critical Dynamics of Compound Erosion in the Pisha Sandstone Area.IOP Conference Series: Earth and Environmental Science.2020,526,012024-012024.https://doi.org/10.1088/1755-1315/526/1/012024.
20. Li,Y.;Xie,Z.X.;Qin,Y.;Sun,Y.Y.Temporal-Spatial Variation Characteristics of Soil Erosion in the Pisha Sandstone Area, Loess Plateau.China. Polish Journal of Environmental Studies.2019,28,2205-2214.https://doi.org/10.15244/pjoes/92940.
21. Wang,R.J.;Yan,F.Fractional vegetation cover and topographic effects in Pisha sandstone area of Northwest China in 2000-2018.PubMed.2020,31,1194-1202.https://doi.org/10.13287/j.1001-9332.202004.005.
22. Zhang,P.;Xiao,P.;Yao,W.;Liu,G.B.;Sun,W.Y.Profile distribution of soil moisture response to precipitation on the Pisha sandstone hillslopes of China.Scientific Reports.2020,10,0-0.https://doi.org/10.1038/s41598-020-65829-w.
23. Tian,Y.;Lu,H.Y.Forest Management Research Based on Tree Growth Model.Highlights in Science Engineering and Technology.2022,11,7-15.https://doi.org/10.54097/hset.v11i.1194.

24. Shi,H.B.;Zhang,F.;Shi,Q.D.;Li,M.G.;Dai,Y.;Zhang,Z.P.;Zhu,C.M.Responses of arid plant species diversity and composition to environmental factors.Journal of Forestry Research.2023,34,1723-1734.https://doi.org/10.1007/s11676-023-01618-1.
25. Jiang,X.Y.;Gao,S.G.;Jiang,Y.;Tian,Y.;Jia,X.;Zha,T.S.Species diversity, functional diversity, and phylogenetic diversity in plant communities at different phases of vegetation restoration in the Mu Us sandy grassland.Shengwu duoyangxing.2022,30,21387-21387.https://doi.org/10.17520/biods.2021387.
26. Li,Z.;Zhang,Z.W.;Wang,Y.J.;Wang,P.C.;Xu,Y.C.;Zhou,Z.X.Influence of anthropogenic disturbances on understory plant diversity of urban forests in Wuhan,Central China.null.2012,0,0-0.https://doi.org/null.
27. Zambon,N.;Johannsen,L.L.;Strauß,P.;Dostál,T.;Zumr,D.;Cochrane,T.A.;Klik,A.Splash erosion affected by initial soil moisture and surface conditions under simulated rainfall.Catena.2021,196,104827-104827.https://doi.org/10.1016/j.catena.2020.104827.
28. Su,X.P.;Li,S.J.;Wan,X.H.;Huang,Z.Q.;Liu,B.;Fu,S.L.;Kumar,P.Understory vegetation dynamics of Chinese fir plantations and natural secondary forests in subtropical China.Forest Ecology and Management.2021,483,118750-118750.https://doi.org/10.1016/j.foreco.2020.118750.
29. Rahman,A.;Khan,N.;Ali,K.;Ullah,R.;Khan,M.E.H.;Jones,D.A.;Rahman,I.U.Plant Species Classification and Diversity of the Understory Vegetation in Oak Forests of Swat, Pakistan. Applied sciences.2021,11, 11372-11372.https://doi.org/10.3390/app112311372.
30. Zhao,Q.;Feng,Y.;Lei,X.;Cao,X.M.;Zou,J.X.;Feng,Y.M.A study on the potential for vegetation restoration in the soft rock area of the Ordos Plateau.Arid Zone Research.2024,41:1583-1592.doi:10.13866/j.azr.2024.09.14.
31. Yang,Y.F.;Wu,L.Y.;Mu,Y.L.;Wei,F.J.;Zhang,C.Q.;Han,X.;Hou,T.Diversity and Biomass of Herbaceous Layer Plants Under Different Types of Platycladus orientalis Plantations.Journal of Northwest Forestry University.2023,38:61-68.doi:10.3969/j.issn.1001-7461.
32. Zhang,H.S.;Jiao,X.D.;Zha,T.G.;Lv,X.Z.;Ni,Y.X.;Zhang,Q.F.;Wang,J.W.Developmental Dynamics and Driving Factors of Understory Vegetation: A Case Study of Three Typical Plantations in the Loess Plateau of China. Forests.2023,14,2353-2353.https://doi.org/10.3390/f14122353.
33. Siswo.;Yun,C.W.;Lee,J.G.Role of Tree Vegetation and Associated Environmental Factors on the Understory Herb-Layer Composition in a Reforested Area: A Study fromKulon Progo CommunityForestry".Diversity.2023,15,900-900.https://doi.org/10.3390/d15080900.
34. Wang,X.X.; Liu,Y.D.Effects of spatial structure on understory vegetation and soil properties in Pinus tabuliformis plantation of different succession types in Beijing.Acta Ecologica Sinica.2023,43,0-0. https://doi.org/10.5846/stxb202112143542.
35. Zou,H.;Gao,G.Y.;Yuan,C.R.;Yang,W.J.Interactions between soil water and plant community during vegetation succession in the restored grasslands on the Loess Plateau of China.Land Degradation & Development.2022,34,1582-1592.https://doi.org/10.1002/ldr.4555.
36. Hu,L.D.;Zhou,H.J.;Huang,Y.Z.;Yao,X.Y.;Ye,S.M.;Yu,S.F.A Study on Plant Species Diversity and Soil Carbon and Nitrogen in Different Cunninghamia lanceolata Stand Types.Ecology and Environmental Sciences.2022,31,451-459.DOI:10.16258/j.cnki.1674-5906.2022.03.003.
37. Wang,L.;Wen,Y.G.;Zhou,X.G.Effects of Mixing Eucalyptus urophylla × E. grandis with Castanopsis hystrix on Understory Vegetation and Soil Properties.Ecology and Environmental Sciences.2022,31:1340-1349.doi:10.16258/j.cnki.1674-5906.2022.07.006.
38. Ferrio,J.P.;Shestakova,T.A.;Castillo,J.D.;Voltas,J.Oak Competition Dominates Interspecific Interactions in Growth and Water-Use Efficiency in a Mixed Pine–Oak Mediterranean Forest.Forests.2021,12,1093-1093.https://doi.org/10.3390/f12081093.
39. Liu,C.G.;Jia,X.X.;Bai,X.Y.;Shao,M.G.Analysis of soil water use by exotic and native vegetation in a semi-arid area and their associated interspecific competition.Science of The Total Environment.2023,905,167066-167066.https://doi.org/10.1016/j.scitotenv.2023.167066.
40 Wang,D.D.;Yuan,Z.J.;Cai,Y.T.;Jing,D.W.;Liu,F.;Tang,Y.;Song,N.G.Characterisation of soil erosion and overland flow on vegetation-growing slopes in fragile ecological regions: A review.Journal of Environmental Management.2021,285,112165-112165.https://doi.org/10.1016/j.jenvman.2021.112165.
41. Špulák,O.;Šach,F.;Kacálek,D.Topsoil Moisture Depletion and Recharge below Young Norway Spruce, White Birch, and Treeless Gaps at a Mountain-Summit Site.Forests.2021,12,828-828.https://doi.org/10.3390/f12070828.
42. Tang,F.Q.;Ma,T.;Tang,J.Y.;Yang,Q.F.;Xue,J.F.;Zhu,C.;Wang,C.Space-time dynamics and potential drivers of soil moisture and soil nutrients variation in a coal mining area of semi-arid, China.Ecological Indicators.2023,157,111242-111242.https://doi.org/10.1016/j.ecolind.2023.111242.
43. Wang,N.;Bi,H.X.;Cui,Y.H.;Zhao,D.Y.;Hou,G.R.;Yun,H.Y.;Liu,Z.H.Optimization of stand structure in Robinia pseudoacacia Linn. based on soil and water conservation improvement function.Ecological Indicators.2022,136,108671-108671.https://doi.org/10.1016/j.ecolind.2022.108671.
44. Tanioka,Y.;Ida,H.;Hirota,M.Relationship between Canopy Structure and Community Structure of the Understory Trees in a Beech Forest in Japan.Forests.2022,13,494-494.https://doi.org/10.3390/f13040494.
45. Crisan,V.;Dincă,L.;Deca,S.S.Analysis of Chemical Properties of Forest Soils from Bacau County.Revista De Chimie.2020,71,81-86.https://doi.org/10.37358/rc.20.4.8045.
46. Dincă,L.;Chisăliță,I.;Cântar,I.C.Chemical Properties of Forest Soils from Romania West Plain.Revista De Chimie.2019,70,2371-2374.https://doi.org/10.37358/rc.19.7.7342.

47. Dong,L.J.;Li,J.W.;Yu,Z.;Bing,M.Y.;Liu,Y.L.;Jing,W.;Hai,X.Y.Effects of vegetation restoration types on soil nutrients and soil erodibility regulated by slope positions on the Loess Plateau.Journal of Environmental Management.2022,302,113985-113985.https://doi.org/10.1016/j.jenvman.2021.113985.
48. Haberstroh,S.;Werner,C.The role of species interactions for forest resilience to drought.Plant Biology.2022,24,1098-1107.https://doi.org/10.1111/plb.13415.
49. Balderas,J.M.;Rodríguez,E.A.;Olivo,A.M.;Costa,A.C.Woody plant community structure and composition of an urban riparian forest in Monterrey metropolitan area, Northeast Mexico1.Journal of The Torrey Botanical Society.2022,149,0-0.https://doi.org/10.3159/torrey-d-21-00030.1.
50. Lever,J.;Krzywinski,M.;Altman,N.Principal component analysis.Nature Methods.2017,14,641-642.https://doi.org/10.1038/nmeth.4346.
51. Liu,J.W.;Hou,K.;Tao,W.D.;Li,H.Y.;He,D.L.;Ma,L.;Tang,H.J.;A spatial distribution-Principal component analysis (SD-PCA) model to assess pollution of heavy metals in soil.Science of The Total Environment.2023,859,160112-160112.https://doi.org/10.1016/j.scitotenv.2022.160112.
52. Yang,Z.H.;Shi,Y.Q.;Li,P.L.;Pan,K.H.;Li,G.Q.;Li,X.G.;Yao,S.Application of Principal Component Analysis (PCA) to the Evaluation and Screening of Multiactivity Fungi.Journal of Ocean University of China.2022,21,763-772.https://doi.org/10.1007/s11802-022-5096-x.
53. Wang,N.;Bi,H.X.;Peng,R.D.;Zhao,D.Y.;Liu,Z.H.Disparities in soil and water conservation functions among different forest types and implications for afforestation on the Loess Plateau.Ecological Indicators.2023,155,110935-110935.https://doi.org/10.1016/j.ecolind.2023.110935.
54. Li,T.J.;Sun,Y.;Wang,L.Y.;Xu,R.;Tigabu,M.;Li,M.;Wang,D.H.Effects of species mixture on understory vegetation, soil properties and bacterial diversity of Acacia cincinnata, Eucalyptus robusta and Acacia mangium plantations in southeastern China.Plant Stress.2023,10,100278-100278.https://doi.org/10.1016/j.stress.2023.100278.
55. Zhou,Y.;Liu,C.H.;Ai,N.;Qin,J.F.;Shi,J.H.;Nan,Z.Z.Soil fauna community characteristics and driving factors of Pinus tabuliformis in the loess region of northern Shaanxi.Catena.2023,229,107196-107196.https://doi.org/10.1016/j.catena.2023.107196.
56. Hrivnák,R.;Bošeľa,M.;Slezák,M.;Lukáč,M.;Svitková,I.;Gizela,J.;Hegedüšová,K.Competition for soil resources forces a trade-off between enhancing tree productivity and understorey species richness in managed beech forests.Science of The Total Environment.2022,849,157825-157825.https://doi.org/10.1016/j.scitotenv.2022.157825.
57. Truax,B.;Fortier,J.;Gagnon,D.;Lambert,F.Planting Density and Site Effects on Stem Dimensions, Stand Productivity, Biomass Partitioning, Carbon Stocks and Soil Nutrient Supply in Hybrid Poplar Plantations.Forests.2018,9,293-293.https://doi.org/10.3390/f9060293.
58. Li,T.T.;Yu,S.Y.;Wu,A.M.;Gu,D.L.;Xu,H.;Hao,J.F.Effects of stand factors on understory species diversity of different plantations in Yunding Mountain.Acta Botanica Boreali-Occidentalia Sinica.2019,39,1463-1471.https://doi.org/null.