Turkish Journal of Agriculture and Forestry

Volume 48 | Number 2 Article 4

4-1-2024

Effect and mechanisms of conifer and broadleaf mixtures on the soil characteristics in limestone mountains

Xueping Zhang

Yuhua Ma

Songling FU

Jingjing QIAN

Qi ZHU

See next page for additional authors

Follow this and additional works at: https://journals.tubitak.gov.tr/agriculture

Part of the Agriculture Commons, and the Forest Sciences Commons

Recommended Citation

Zhang, Xueping; Ma, Yuhua; FU, Songling; QIAN, Jingjing; ZHU, Qi; FENG, Chun; LI, Zihao; ZHU, Wenhao; and CHEN, Han (2024) "Effect and mechanisms of conifer and broadleaf mixtures on the soil characteristics in limestone mountains," *Turkish Journal of Agriculture and Forestry*: Vol. 48: No. 2, Article 4. https://doi.org/10.55730/1300-011X.3174
Available at: https://journals.tubitak.gov.tr/agriculture/vol48/iss2/4

This Article is brought to you for free and open access by TÜBİTAK Academic Journals. It has been accepted for inclusion in Turkish Journal of Agriculture and Forestry by an authorized editor of TÜBİTAK Academic Journals. For more information, please contact pinar.dundar@tubitak.gov.tr.

Effect and mechanisms of conifer and broadleaf mixtures on the soil characteristics in limestone mountains

Authors

Xueping Zhang, Yuhua Ma, Songling FU, Jingjing QIAN, Qi ZHU, Chun FENG, Zihao LI, Wenhao ZHU, and Han CHEN

This article is available in Turkish Journal of Agriculture and Forestry: https://journals.tubitak.gov.tr/agriculture/vol48/iss2/4

Turkish Journal of Agriculture and Forestry
http://journals.tubitak.gov.tr/agriculture/
Research Article

Turk J Agric For
(2024) 48: 199-211
© TÜBİTAK
doi:10.55730/1300-011X.3174

Effects and mechanisms of conifer and broadleaf mixtures on soil characteristics in limestone mountains

Xueping ZHANG[1,2], Yuhua MA[3], Songling FU[1], Jingjing QIAN[2], Qi ZHU[4], Chun FENG[1], Zihao LI[2], Wenhao ZHU[2], Han CHEN[5,*]
[1]School of Forestry and Landscape Architecture, Anhui Agricultural University, Hefei, China
[2]College of Agriculture, Anhui Science and Technology University, Fengyang, China
[3]College of Civil and Architecture Engineering, Chuzhou University, Chuzhou, China
[4]State Key Laboratory of Urban and Regional Ecology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing, China
[5]Faculty of Natural Resources Management, Lakehead University, Thunder Bay, Canada

Received: 01.09.2023 • **Accepted/Published Online:** 10.01.2024 • **Final Version:** 01.04.2024

Abstract: In restoring the limestone mountain ecosystem, the core scientific issue for achieving ecological restoration and ecosystem stability lies in understanding the interaction mechanism between vegetation and soil. To address this, we focused on four types of artificial forest communities, each 30 years old, with varying ratios of coniferous and broad-leaved trees (0%–20%, 20%–50%, 50%–80%, 80%–100%) in typical limestone mountainous areas of the northern subtropical region. These forest communities were selected as research subjects to assess understory vegetation diversity, litter fall, and fine root characteristics. The study investigates the influence of various mixing ratios on the restoration of understory vegetation and soil systems. The findings reveal significant differences in litter fall stock, water capacity, annual decomposition rate, nutrient change rate, and fine root biomass of litter fall among different mixing proportions. With an increase in the proportion of coniferous trees, both standing litter fall and annual yield exhibit a decrease. Consequently, an effective strategy for restoring and enhancing fragile ecosystems in limestone mountainous areas involves establishing mixed forests or conducting forest transformations based on a moderate mixing proportion.

Key words: Limestone mountains, plantation stands, community structure, soil characteristics, stoichiometric characteristics

1. Introduction

Afforesting limestone mountainous areas poses significant challenges. The terrain is susceptible to soil erosion and vegetation degradation, rendering it one of the most severely fragile ecological regions. Globally, it stands out as a crucial research area for ecological restoration (Feng et al., 2022; Arji et al., 2022). In these fragile habitats, characterized by limited nutrients and harsh environments, vegetation is sparse, and biodiversity is low. Simultaneously, issues like the imprudent arrangement of vegetation in artificial restoration have compromised the stability of fragile ecosystems. These factors have emerged as pivotal obstacles hindering the sustainability and positive ecological outcomes of restoration projects. The success of restoring artificial vegetation systems hinges on the synergistic interactions among plants, soil, and microbes, necessitating the construction of a relatively comprehensive system (Kalacska et al., 2007; Arji et al., 2021; Gholami et al., 2023).

In forest ecosystems, variations in the quality of upper litter fall between broad-leaved and coniferous forest species affect litter fall decomposition and soil nutrient availability. During the degradation of litter fall, it can regulate soil acidity and alkalinity, improve soil structure, and provide essential nutrients for plants in the soil. It can also accelerate biological cycling and promote soil development, contributing significantly to the maintenance of soil fertility and other vital aspects (Prescott et al., 2000; Gholami et al., 2022). The soil experiences noteworthy changes in the content of nutrients necessary for plant growth. Additionally, there are differences in the relative abundance and soil enzyme activity of soil microorganisms in communities with different mixing ratios (Salehi Sardoei, 2023).

The feedback effects of different trees on soil properties such as C, N, P, water content, pH, and others vary. Soil fertility can be assessed through the stoichiometric characteristics of soil C, N, and P (Yazdanpanah-Ravari,

* Correspondence: chenhan2014310@163.com

This work is licensed under a Creative Commons Attribution 4.0 International License.

2022). Various factors, including litter fall decomposition products and plant root activity, have a certain impact on the organic matter content of the soil in different forest types. These factors reflect the mineralization and fixation of soil nutrients. Numerous studies have highlighted the role of forest litter in reducing soil erosion, which is crucial for improving soil fertility and conserving water sources (Omidmehr, 2022). There exists a notable interaction between forest litter fall and soil microorganisms. However, this relationship tends to vary depending on differences in terrain conditions, plant species, and soil types. Currently, there is limited research on the analysis of plant-soil interaction and restoration response mechanisms from microbial communities (Pocock et al., 2012; Ganjali et al., 2022). The study focuses on artificial forests with different mixing ratios in limestone mountainous areas, using the "vegetation-microbiota-soil" nexus as a research entry point. The study delves into the internal correlation and interaction mechanisms of ecosystems in fragile habitat areas, specifically examining the vegetation-soil properties, nutrient dynamics, and feedback relationships with microbial communities within limestone mountain artificial forests. The aim is to elucidate the stability mechanism of limestone mountain artificial forest ecosystems.

2. Related work

Limestone mountainous areas are characterized by numerous bare rocks, with the developed soil containing higher levels of calcium and magnesium. The soil layer is thin and barren. Additionally, there is a significant issue of surface water leakage in limestone mountainous areas, leading to inadequate water supply. These challenges constrain the types of vegetation suitable for growth in the environment, rendering the limestone mountain ecosystem a classic example of a fragile ecological area (Rheault et al., 2015). When the regional environment undergoes damage, the recovery of soil and vegetation becomes challenging, and the harm incurred is often irreversible. The limestone mountain ecosystem, offering relatively scarce available resources, intensifies the contrast between protection and development, posing a considerable challenge to sustainable management. Forest management methods geared towards maximizing economic benefits may not be conducive to maintaining ecosystem stability in limestone mountainous areas, given their high sensitivity to ecological variations (Penny et al., 2013). Opting for a forest management approach that minimizes ecological losses, or has limited impact, while ensuring satisfactory economic benefits appears more appropriate.

In recent years, research on limestone mountainous ecosystems has deepened and refined, with a specific focus on the influence of vegetation restoration on the underground ecosystem, soil, and water supply in these areas. Variations in the types of tree species suitable for growth in limestone mountainous areas play a significant role. The composition, structure, and pattern of natural vegetation in limestone areas have a discernible impact on regional water balance (Zhang et al., 2013). The duration of closure affects vegetation growth in limestone mountainous areas, consequently affecting fine root biomass. However, positive effects are observed only within a specific timeframe. Additionally, there is a negative correlation between soil depth and fine root biomass (Zhou et al., 2014). The closure time, influenced by different forest types and study areas, also impacts the enzyme activity of limestone soil, with stronger effects observed within the 10 to 30 years range. Extensive research on soil improvement and ecological restoration in limestone mountainous areas has demonstrated that manure can improve soil fertility in limestone (Ratke et al., 2014).

Numerous studies have highlighted the role of forest litter fall in reducing soil erosion, playing a crucial part in improving soil fertility and conserving water sources. Kardol et al. emphasized that the loose layer structure of litter fall enhances the soil's water absorption capacity, reducing the impact of water flow on the ground and achieving soil and water conservation (Kardol et al., 2010).

To measure forest litter fall, collected samples are classified and weighed. Changes in vegetation can be assessed by examining variations in litter fall composition and volume. Paredes et al. (2015) pointed out that factors influencing litter fall decomposition include soil properties and microbial characteristics). Fu et al. asserted that litter fall plays a crucial and irreplaceable role in maintaining the structure of ecosystems, acting as a vital link between soil and ecosystems. Litter fall serves as a significant component of ecosystem energy conversion. The process of nutrient cycling in ecosystems is manifested through the rate of litter fall decomposition and nutrient return, influencing the nutrient absorption of plants (Fu et al., 2015).

The root system serves as a crucial organ responsible for absorbing water and nutrients from the soil. Simultaneously, it plays a vital role in synthesizing organic compounds such as amino acids. Among the various root components, fine roots are particularly significant. Although their biomass proportion in the root system may be relatively small, they substantially contribute to increasing the effective absorption surface area. Consequently, the number of fine roots can, to some extent, serve as an indicator reflecting the health status of plants (Paydar et al., 2014). Fine root biomass is indicative of the root system's capacity to absorb soil nutrients. As seedlings mature, there is an observed increasing trend in the root-to-shoot ratio, the presence of coarse roots, fine roots, and the number of branches (Hernández-Clemente et al., 2009). Root biomass plays a crucial role in the absorption and cycling of water and nutrients in plants. The root system of tree species, with its complex branching system exhibiting morphological and physiological heterogeneity, contributes to maintaining ecosystem stability and is significant for ecosystem productivity. The various forms and biomass changes observed in the root system can be considered integral to the functioning of the forest ecosystem (Hedwall et al., 2015). While coarse roots are important for nutrient storage and transportation, fine roots take center stage in productivity and ecosystem carbon cycling.

Previous studies have addressed the vegetation dynamics of limestone forest ecosystems to differing extents. However, there is a limited body of research on the synergistic restoration mechanism involving vegetation, soil, and microorganisms. Therefore, further research is needed on the influencing factors of community construction and biodiversity maintenance in limestone mountainous areas, exploring the ecological mechanisms and driving factors of ecosystem restoration. This research is anticipated to offer valuable insights for the scientific development of forest management plans.

3. Methodology

3.1. Sample site selection

The research focuses on the forest land within the Jiushan National Forest Park scenic area, characterized by minimal human interference. Utilizing afforestation data from Dayinshan Forest Farm, specific experimental plots were chosen. The selected sample plots share similar site factors, including altitude, slope direction, slope position, and slope, and have the same forest age (afforested in 1986). Furthermore, the designated sample plots are situated at a considerable distance from the forest edge to minimize external influences.

To investigate the impact of the mixing ratio of coniferous and broad-leaved trees, 12 plots were established, representing four coniferous tree ratios: 0%–20%, 20%–50%, 50%–80%, and 80%–100%. Within each coniferous tree ratio, three plots were selected. Each plot was equipped with a sample area measuring 20 × 20 m^2.

3.2. Experimental methods

3.2.1. Collection and treatment of litter fall

In each sample plot, 10 randomly placed 1 × 1 m^2 sample boxes were set up to collect the existing litter. The collected litter was separately air-dried and weighed. Following this, the litter fall was classified, weighed, and recorded as either undecomposed or semidecomposed. The upper layer of the existing litter fall predominantly consists of an undecomposed layer, preserving the original state of leaves, branches, and fruits. On the other hand, the lower layer of the existing litter fall is primarily a semidecomposed layer, exhibiting a dark brown to black color. In this layer, much of the litter has already undergone fragmentation. For each part, there is essentially no distinct appearance outline, making them indistinguishable (Schafer et al., 2014). The litter fall was classified and placed in an oven, where the sample was dried to a constant weight at 65 °C and then weighed and recorded. Employing the mechanical placement method, five litter fall collection points were established. At each collection point, a 0.8×0.8 m^2 litter fall collection basket was set up. Litter fall within the box was collected in the middle of the last month of each quarter. Subsequently, the litter fall at each collection point was classified and weighed according to categories such as oak leaves, miscellaneous leaves, branches, fruits, and others. After classification, it was dried to a constant weight at 65 °C, and the final weight was recorded.

3.2.2. Litter fall water-holding capacity

To determine the water capacity of undecomposed and semidecomposed litter fall, 50 g of each type was weighed and placed in separate 100-mesh bags. The bags were marked and immersed in water. After specific intervals of 5 min, 30 min, 6 h, 12 h, and 24 h, the net bags were taken out of the water and reweighed. The water capacity of the litter fall can be calculated using formula (1).

$$M = [P - Q] \times 10 \tag{1}$$

In formula (1), M represents the water-holding capacity of litter fall (kg/hm^2), p represents the wet weight of litter fall (g/m^2), and Q represents the drying weight of the litter fall (g/m^2). According to formula (1), the water-holding capacity of the litter fall can be obtained as shown in formula (2).

$$w = \frac{M}{Q} \times 100\% \tag{2}$$

3.2.3. Litter fall decomposition rate

The net bag method was employed to investigate the decomposition status of leaves in litter fall. The collected and air dried leaves from the litter fall basket were weighed and loaded into a 20 × 10 cm^2 nylon mesh bag. The weighed sample was then placed in a 65 °C oven and dried until a constant weight was achieved. The moisture content of the air-dried litter leaves was calculated. After drying, the leaf litter was crushed, and a 100-mesh sieve was utilized for sieving, packaging, and determining the chemical composition.

3.2.4. Nutrient content in litter fall

After wrapping the sample with aluminum foil and weighing it, the litter fall sample's total organic C and total N content were measured using the Euro EA3000 elemental analyzer. Following the boiling and filtering of P, K, Ca, and Mg, the, a test solution was prepared. The FIAStar5000 flow injection instrument is employed to measure P. For K, Ca, and Mg, the content in the litter fall samples was determined using the atomic absorption spectrophotometer (TAS-990AFG type) (Moreno-Gutiīerrez et al., 2015).

3.2.5. Fine root standing stock

In each sample, 5 random points were selected at a 2-meter distance from the artificial tree, covering upper, middle, and lower slopes. To ensure the scientific integrity of the test materials, a flat shovel was utilized to evenly scoop sample blocks around the roots. Five samples were taken from each location, marked, and placed in individual plastic bags. These bags were then transported back to the laboratory and stored in a 4 °C freezer. The root samples underwent a process where they were soaked in clean water and then rinsed with running water. Using a sieve with a pore size of 0.5 mm, the samples were screened to remove the majority of soil, organic matter residue, and other impurities. The root systems were separated and placed in clean water, removing all remaining soil. Following the classification criteria for root systems, those with a diameter of ≤2 mm were classified as fine roots, while others were classified as coarse roots. Live and dead roots were further classified based on their color and morphology.

3.2.6. Root morphology and biomass

The classification of fine root order was structured as follows: the thinnest root in the root sequence, furthest from the root axis and without branches, was labeled as the Level I root. The parent root of the upper-level branch was assigned as the Level II root, and this grading continued gradually ascending up to the Level VII root. The root scanning analysis system, Win-RHIZO (Pro 2005b), was employed to scan and analyze fresh samples of processed fine and coarse roots, providing pertinent data on the quantity, length, diameter, and surface area of both fine and coarse roots.

The root samples were placed in a 65 °C oven for drying treatment. After baking to a constant amount, the dry weight of each root system was measured. The biomass for each root sample is expressed in formula (3).

$$D\,(g \cdot m^{-2}) = G\,(g\,/\,S) \qquad (3)$$

In formula (3), S is the sampling area (m^2), D is the root biomass, and G is the root mass.

3.3. Statistical processing of experimental data

To investigate the seasonal dynamics of community structure and forest litter fall, correlation analysis is performed using the "ggcor" package in SPSS 19.0 and R.

4. Analysis of results

4.1. Existing litter fall

The present quantity of forest litter fall encompasses both undecomposed and semidecomposed components. The proportion of semidecomposition serves as an indicator of the decomposition status of understory litter fall, as depicted in Figure 1. The forest with a coniferous ratio of 0%–20% exhibits the greatest amount of litter fall, surpassing the forests with ratios of 20%–50%, 50%–80%, and 80%–100% by 38.85%, 106.63%, and 70.92%, respectively. There is a significant difference in the existing amount of litter fall between forests with coniferous tree proportions of 50%–80% and 80%–100%. However, there is no significant difference in the proportion of semi-decomposition of litter fall among forests with different mixing proportions. The forest with a coniferous tree proportion of 50%–80% shows a slightly higher proportion. Despite having the smallest total amount, it exhibits a higher semi-decomposition amount. This suggests that the decomposition status of existing litter fall in forests with a coniferous tree proportion of 50%–80% is favorable.

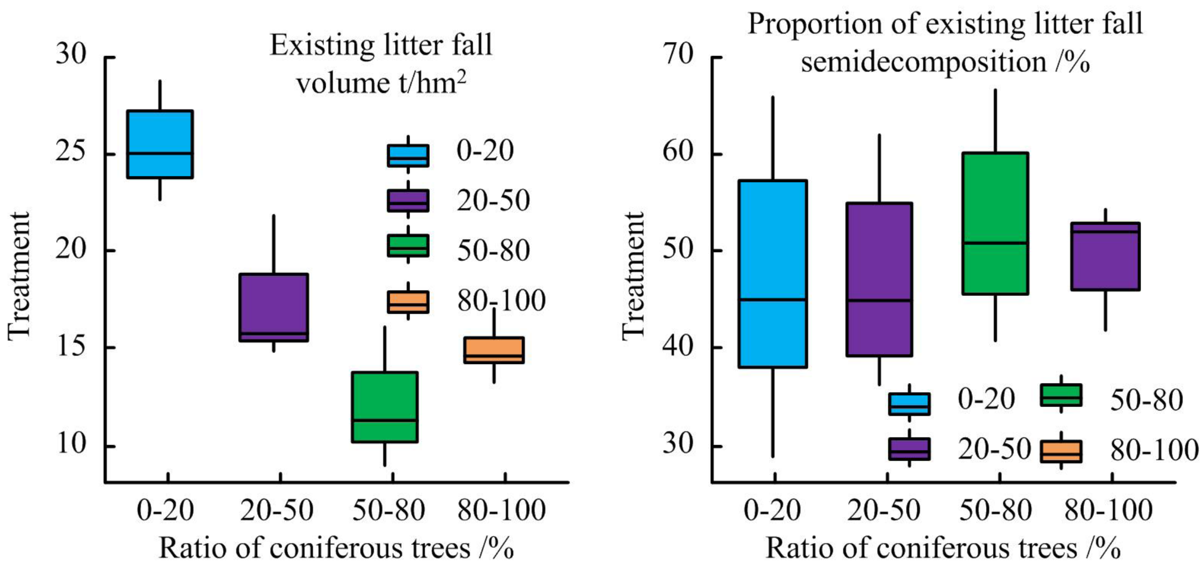

Figure 1. The inventory amount of litter and the proportion of half-decomposed litter in the forest.

4.2. Water-holding capacity of existing litter fall in the forest

Figure 2 illustrates the water-holding capacity of existing litter in forests with different mixing proportions, aiding in the analysis of factors affecting the soil environment. This investigation further delves into the mechanisms affecting soil microorganisms and soil enzyme activity. A comparison is made between the water-holding capacity of semidecomposed and undecomposed litter fall in the forest at different time periods. With the exception of the data for semidecomposed litters at 24 h, coniferous forests with a proportion of 50%–80% exhibit the highest water-holding capacity for both semidecomposed and undecomposed litters. The water-holding capacity of semidecomposed and undecomposed litter fall in coniferous forests with a proportion of 20%–50% ranks second across multiple time periods.

4.3. Seasonal changes and annual yield of litter fall

Figure 3 depicts the seasonal variation of litter fall in the mixed forest of coniferous and broad-leaved trees. The total amount of litter fall in forests with a coniferous ratio of 0%–20% is higher. Specifically, during the relatively dry and cold winter and spring months (December and March), the litter fall is significantly higher than in forests with other ratios. For forests with a coniferous proportion of 50%–80%, the litter fall is higher than the proportion in September. There is a significant difference between 0%–20% and 20%–50%, while no significant difference is observed in litter fall within the mixed proportion forest during the summer months.

Figure 4 illustrates the changes in the composition of litter fall. In forests where the proportion of coniferous trees is 0%–20%, the highest proportion of Quercus acutissima leaves is observed, resulting in relatively single litter fall composition. Conversely, when the proportion of coniferous trees is 80%–100%, the proportion of Masson pine leaves is relatively high, and these leaves are known for being challenging to decompose. For forests with proportions of coniferous trees between 20%–50% and 50%–80%, the proportion of litter components is

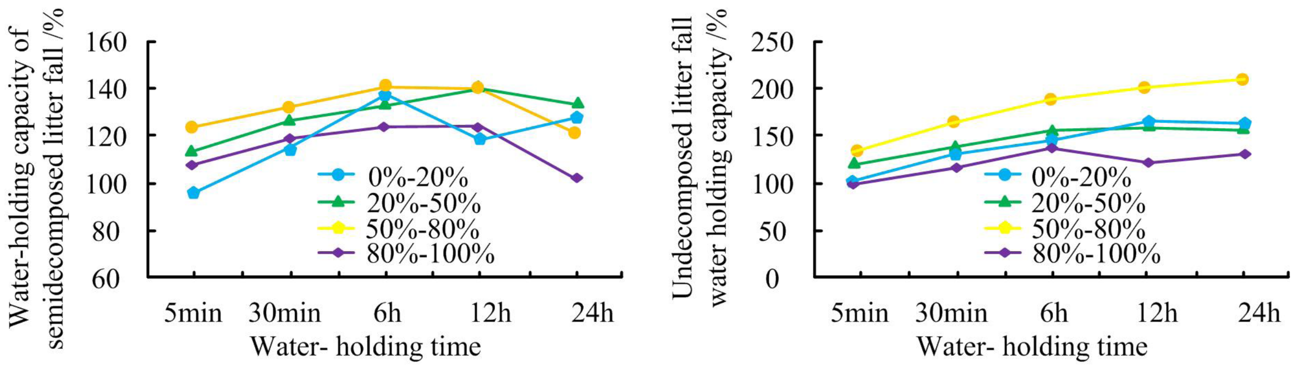

Figure 2. Water retention of undecomposed and semidecomposed litter in forests.

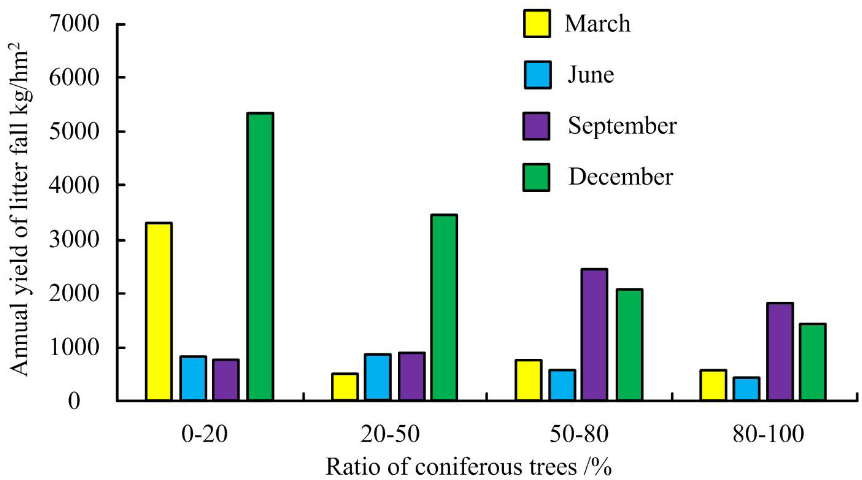

Figure 3. Seasonal variation of litter in plantations.

more uniform. Notably, in forests with a coniferous tree proportion of 50%–80%, the number of fallen branches is the least among the observed components.

4.4. Decomposition of litter fall

Table 1 presents the seasonal changes in litter fall. The quality of litter fall in each quarter is compared to the initial quality. As the proportion of coniferous trees increases, both the monthly average decomposition rate and annual weight loss rate of litter fall exhibit a downward trend. Among the four mixing ratios of coniferous and broad-leaved trees, the forest with a coniferous tree ratio of 0%–20% demonstrates the highest annual weight loss rate of litter. The weight loss rates are 8.93%, 11.46%, and 12.26% higher than those of 20%–50%, 50%–80%, and 80%–100%, respectively, all showing significant differences.

The decomposition rate of litter fall in different seasons varies with different mixing ratios of needle and broadleaf. Specifically, the decomposition rates of coniferous trees in forests with a proportion of 0%–20% and 80%–100% follow the same trend: decreasing over time in the order of summer > autumn > winter > spring. On the other hand, the decomposition rate variation pattern in coniferous forests with a proportion of 20%–80% is summer > autumn > spring > winter. The difference between the two patterns is only significant between June and September.

For all four mixing ratios of needle and broadleaf, there is a peak in litter fall decomposition rates from March to June, with no significant differences in decomposition rates during this period. From July to September, coniferous trees with a ratio of 50%–80% exhibit the highest decomposition rate, which is significantly different compared to coniferous trees with a ratio of 80%–100%.

4.5. Seasonal changes of nutrients in litter fall

Figure 5 illustrates the seasonal changes in nutrient content of litter fall. The highest peak of C content in the 50%–80% and 80%–100% forest types occurs in December at 496.6 g/kg and 460.6 g/kg, respectively. For the 20%–50% proportion of *Quercus acutissima* forest, the highest peak of C content is 451.98 g/kg in March, while the lowest value is 347.99 g/kg in September. In the 80%–100% ratio, the

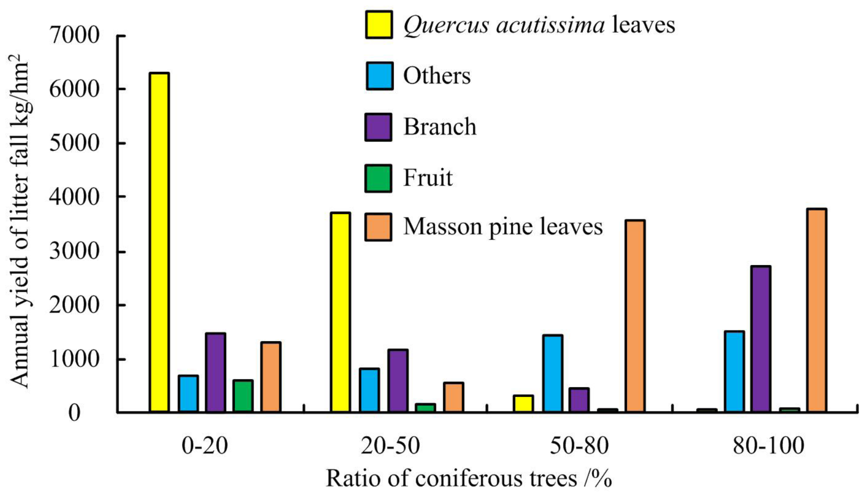

Figure 4. Composition changes of litter in plantations.

Table 1. Decomposition rates of various forest litter in plantations with different mixing ratios.

Conifer ratio %	Decomposition rate (%)				Average monthly/%	Annual weight loss rate/%
	3–6 months	7–9 months	10–12 months	1–3 months		
0–20	29.47 ± 4.39a	17.24 ± 5.66ab	7.33 ± 5.06a	–0.30 ± 1.46a	4.48a	53.73a
20–50	27.73 ± 5.14a	14.36 ± 6.78ab	1.07 ± 1.41b	1.64 ± 0.42a	3.73a	44.80b
50–80	23.47 ± 2.81a	18.68 ± 1.34a	–0.76 ± 1.24b	0.88 ± 0.11a	3.52a	42.27b
80–100	24.00 ± 1.06a	13.37 ± 2.86b	5.65 ± 2.86a	–1.56 ± 1.16a	3.46a	41.47b

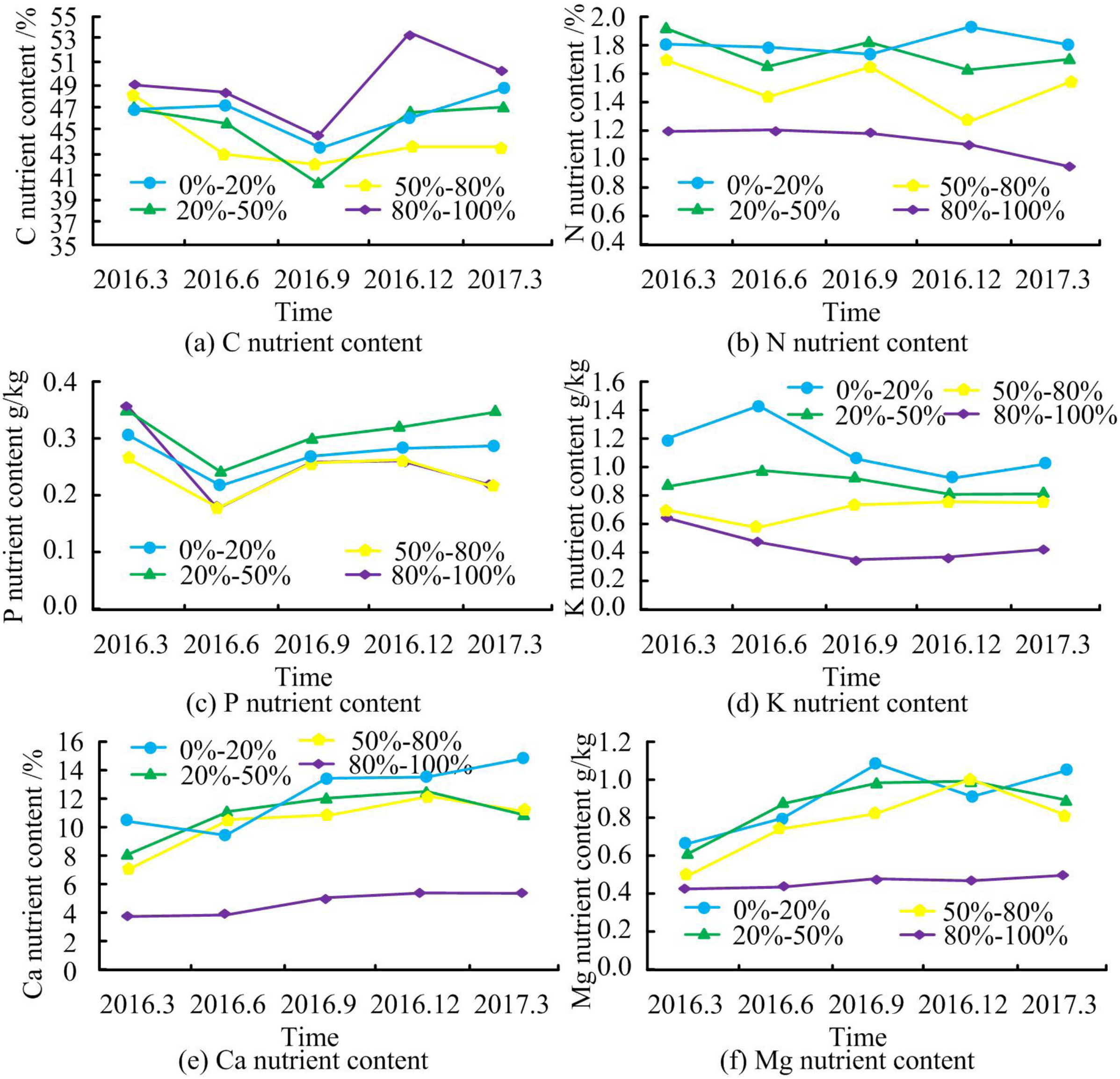

Figure 5. Seasonal variation of litter nutrients in plantations.

content of N, P, and K shows an overall downward trend over time. The decreasing trend of K element content is the most significant, with a maximum value of 2.42 g/kg and a minimum value of 1.29 g/kg.

During the decomposition process, the total content of P and K elements in the 80%–100% forest type is higher than that in the 20%–50% and 50%–80% forest types. In coniferous forests with a proportion of 20%–50%, the content of Ca and Mg elements exhibits a decreasing trend with seasonal changes. On the other hand, the content of Ca and Mg elements in the 50%–80% and 80%–100% forest types shows an overall upward trend over time.

4.6. Changes in root biomass under different mixing ratios

In forests with a coniferous ratio of 20%–50%, the biomass of live fine roots increases by 41.83%, 22.45%, and 50.98% compared to 0%–20%, 50%–80%, and 80%–100%, respectively. These differences are significant, as shown in Figure 6. Additionally, the biomass of dead fine roots in coniferous forests with a proportion of 50%–80% is higher than that in other forests, potentially providing more nutrients for the soil.

4.7. The influence of different mixing ratios on root order

The influence of different mixing ratios on root order is presented in Table 2. In forests with a coniferous ratio of

20%–50%, the percentage of roots with a root number of 1 is higher than in other types. As the root order numbers increase, the advanced roots (root order numbers >2) in the four mixing ratios sharply decrease. Consequently, regardless of the mixing ratio proportion, those with one or two root numbers represent a larger proportion. The prevalence of low-level roots suggests active root systems with high efficiency in water and inorganic salt absorption.

4.8. The effect of different mixing proportions on root length

From Figure 7, it is evident that the total length of both coarse and fine roots is longer in forests with coniferous tree proportions of 20%–50% and 50%–80%. Specifically, the fine roots in a mixing forest with a coniferous ratio of 20%–50% increase by 23.55% compared to 0%–20%, showing a significant difference compared to forests with a coniferous ratio of 80%–100%. This difference may be attributed to the more suitable spatial distribution of underground roots in mixing forests, resulting in less competition. Consequently, the total length of fine roots is significantly larger than in the other two mixing ratios.

4.9. The effect of different mixing proportions on root surface area

As depicted in Figure 8, the fine root surface area is the largest in forests with a coniferous ratio of 20%–50%. A significant difference is observed when compared to

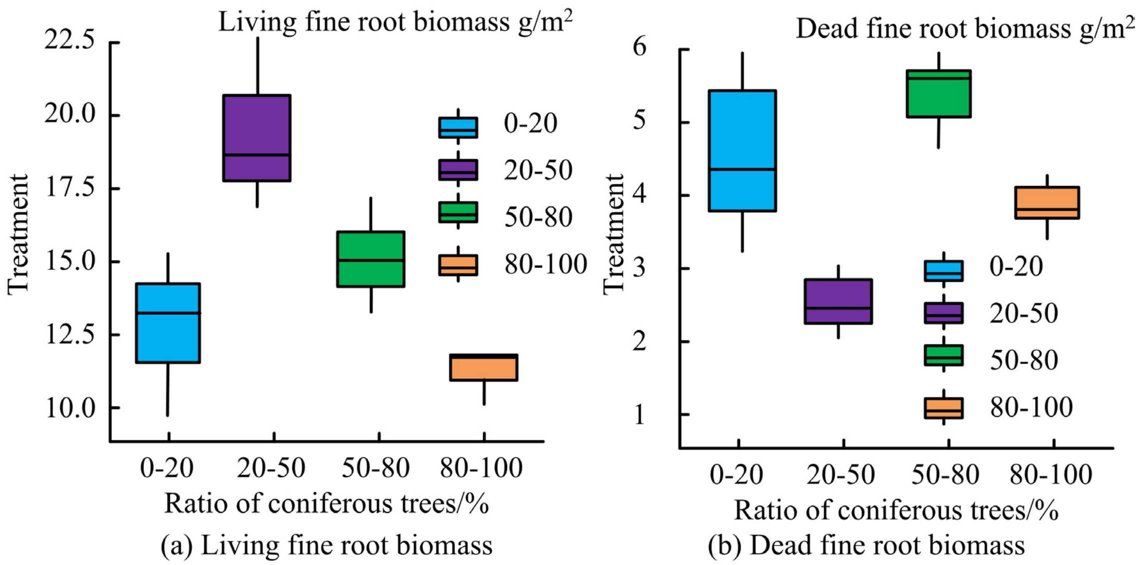

Figure 6. Biomass of fine root in plantations.

Table 2. Changes in the number of root sequences in different mixing ratios.

Ratio of coniferous trees /% Root order		0–20	20–50	50–80	80–100
I	Number	230	254	284	249
	Proportion%	40	42.43	43.76	39.84
II	Number	240	237	253	266
	Proportion%	41.74	39.52	38.98	42.56
III	Number	92	93	95	93
	Proportion%	16	15.54	14.63	14.88
IV	Number	11	3	14	14
	Proportion%	1.92	2.13	2.16	2.24
V	Number	1	2	2	3
	Proportion%	0.17	0.34	0.32	0.48
VI	Number	1	0	1	0
	Proportion%	0.17	0	0.15	0

coniferous trees in forests with a ratio of 80%–100%. The growth and distribution of fine roots are influenced by the proportion of coniferous tree distribution. Environments with an appropriate mixing ratio in the forest have a promoting effect on the growth of fine roots.

4.10. The effect of different mixing proportions on root volume

As shown in Figure 9, the forest with a coniferous ratio of 20%–50% exhibits the largest volume of fine roots, with a significant difference compared to forests with coniferous tree proportions of 50%–80% and 80%–100%. This observation suggests that mixing forests may enhance soil physical conditions and foster the growth of fine roots, resulting in a larger total volume.

4.11.Correlation analysis between understory vegetation and litter fall volume

The Shrub.D and Shrub.H, with coefficients of –0.90 and –0.78, demonstrate a highly significant negative correlation between different mixing proportions of artificial forests and the existing amount of litter fall, as shown in Figure 10. The Herb.D, Herb.H, and Herb.Jsw are also significantly negatively correlated, with coefficients of –0.74, –0.63, and –0.60, respectively.

5. Discussion

The analysis of litter fall volume and environmental factors under different coniferous and broad-leaved mixing ratios in limestone mountain forests reveals a

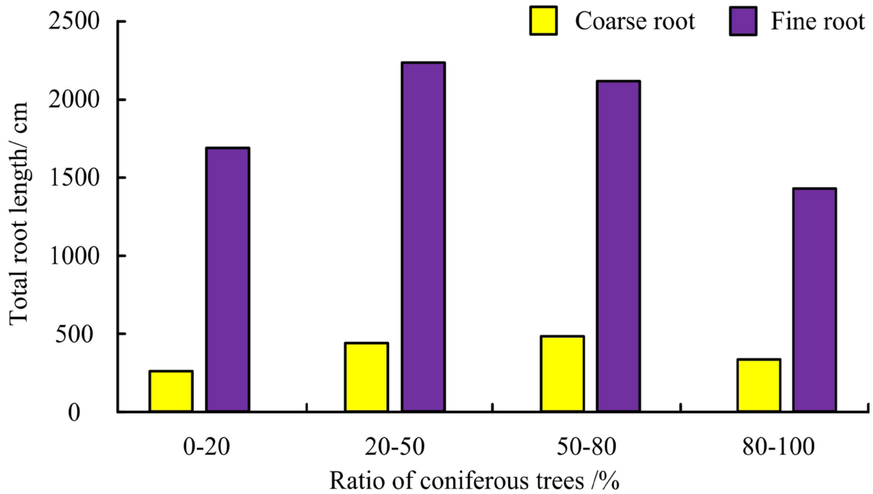

Figure 7. Length of fine and coarse roots in forests.

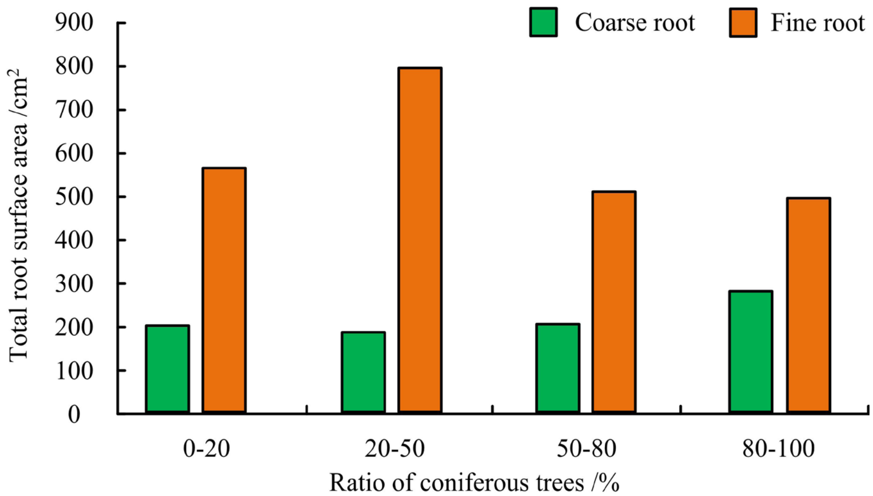

Figure 8. Total surface of fine and coarse roots in forests.

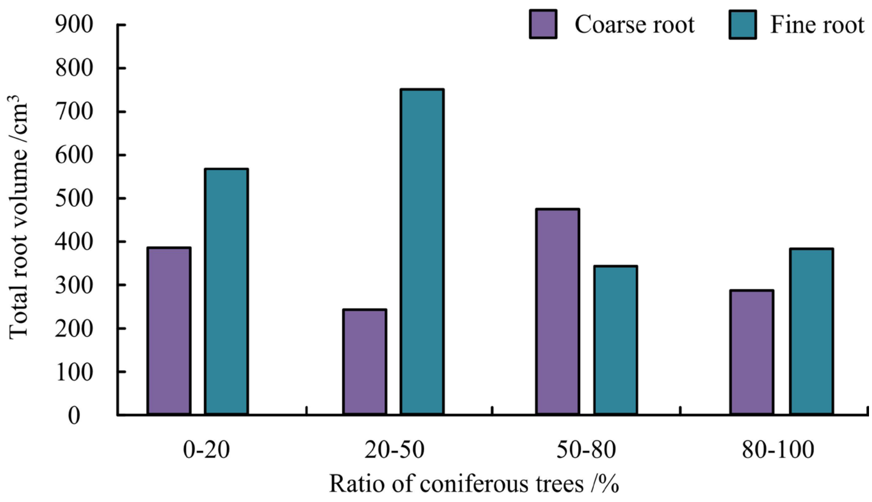

Figure 9. Total volume of fine and coarse roots in forests.

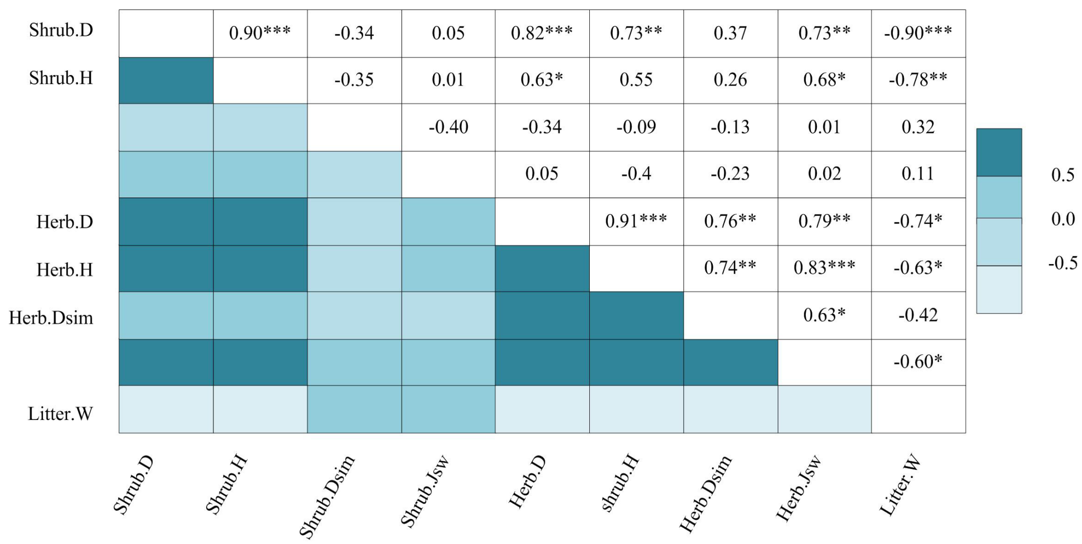

Figure 10. The correlation analysis between litter amount and understory vegetation diversity.

significant correlation between the existing litter fall and air temperature, humidity, and soil temperature. The amount of litter fall in artificial forests with different mixing proportions exhibits significant seasonal changes. Previous studies have indicated that factors contributing to an increased amount of litter fall and an accelerated decomposition rate include monthly average temperature and rainfall, which are positively correlated within a certain range (Fritschie et al., 2014). In this experiment, the decomposition rate is highest from March to June among the four mixing ratios. This trend is determined not only by changes in monthly average temperature but also directly linked to rainfall.

Litter decomposition is the process of converting organic matter into CO_2 and inorganic nutrients, assisted by natural processes such as crushing and forest eluviation. The crushing effect is influenced by changes in temperature and humidity in the forest. In a humid environment, litter fall undergoes continuous degradation influenced by eluviation (Bergeron et al., 2014). The nutrients provided by the crushed and degraded litter fall become a source of energy for microbial growth and reproduction. More microorganisms thrive in the litter fall during this process. Microorganisms can secrete a large amount of extracellular enzymes, continuously decomposing the litter fall to meet their own nutrient needs (Jalilian, S., 2022; Hosseini

Beryekhani, S. A., 2021). Therefore, the observed results during the experiment may differ from expectations due to the significant increase in nutrient content provided by a large number of microorganisms breeding during the decomposition (Chen et al., 2014).

Microbial activity is generally positively correlated with forest temperature and regional rainfall. Appropriate temperature and abundant rainfall directly increase microbial activity, accelerating the decomposition rate of litter fall. However, eluviation increases with rising rainfall, leading to an increased effective nutrient loss rate in litter fall (Bose et al., 2016). There is no significant change in the proportion of each component in the litter fall under different mixing proportions. Moreover, the variations in nutrient concentration in litter fall may be directly related to the nutrient concentration before withering, which requires further verification.

Research has revealed significant differences in the content of C, N, and P in the litter fall of the same mixing proportion between different seasons. This may represent a mechanism for plants to preserve their own nutrients, which is associated with climate change and the plant growth period (Maisto et al., 2011). The increase or decrease of plant litter fall is significantly correlated with temperature changes, leading to variations in the nutrient transfer rate and ensuring that the plant maintains an appropriate nutrient content. In this experiment, differences in nutrient content among different community structures in each quarter may also be related to factors such as temperature, climate, and light.

Fine roots can quickly absorb nutrients and be rapidly degraded by microorganisms. Therefore, the vast majority of carbon in the soil comes from plant fine roots, making them crucial in various ecosystems (Nowroz, 2021). Fine roots play a significant role in carbon allocation, nutrient cycling, and energy flow. The morphological characteristics of fine roots serve as important indicators, directly reflecting a plant's ability to absorb water and nutrients (Fu et al., 2000). Coarse roots, on the other hand, anchor plant bodies in the soil, absorb water and inorganic salts, transport them upwards, and may also function as nutrient storage and reproduction sites (Almasi, 2021). Key morphological indicators affecting plant growth include root length, surface area, volume, and biomass. Root length and surface area in root functional traits are essential indicators for plants in absorbing water and nutrients, while the volume and biomass of fine roots reflect the efficiency of nutrient absorption in root biomass (Sun et al., 2015). Forests with coniferous tree proportions of 20%–50% and 50%–80% exhibit higher fine root biomass compared to the 0%–20% proportion. This fine root biomass is significantly higher than that of coniferous trees with a proportion of 80%–100%. When the mixing ratio is altered, the total length of fine roots is significantly higher than the other two types. The total volume and surface area surpass those of coniferous forests and are significantly higher than those of broad-leaved forests. There is a significant difference in the sensitivity of coarse and fine roots to changes in the proportion of coniferous trees.

The mixing ratio has an impact on the amount of litter fall and root biomass. The litter capacity of coniferous trees with a ratio of 20%–50% and 50%–80% is greater than that of coniferous trees with a ratio of 0%–20% and 80%–100%. The annual litter yield, litter decomposition rate, and existing litter fall volume of coniferous forests with a ratio of 20%–50% and 50%–80% fall between those of 0%–20% and 80%–100%. There is no significant difference in fine root biomass and coarse root biomass between different mixing ratios. Compared with other proportions, coniferous trees with a proportion of 20%–50% and 50%–80% exhibit a decrease in dry weight and an increase in fresh weight.

The mixing ratio influences root biomass, morphology, and distribution. In the mixing forest where the proportion of coniferous trees is 20%–50%, the soil surface root biomass is significantly higher than in other stands. The dead fine root biomass of coniferous trees with a proportion of 50%–80% is higher than that of other ratios. The total length of coarse and fine roots in coniferous forests with a ratio of 20%–50% and 50%–80% surpasses other ratios. Among them, coniferous trees with a proportion of 20%–50% have the highest total root area and volume, with significant differences. The growth status of underground roots in forests with coniferous tree proportions of 20%–50% and 50%–80% is better than in other proportions. The growth and distribution of root systems in forests with a coniferous ratio of 20%–50% are better. The primary factor influencing the characteristics of litter fall and fine roots in different mixing proportion forests is plant diversity. Shrub.D and Shrub.H show a highly significant negative correlation with the standing amount of litter. Herb.D, Herb.H, and Herb.Jsw are also significantly negatively correlated.

6. Conclusion

The biodiversity and ecosystem stability of mixed forests are of great significance for the region's ecosystem. The characteristics of mixing coniferous and broad-leaved forests at different proportions were explored. According to the experiment, firstly, the mixing ratio affects litter fall and root biomass. The litter fall water-holding capacity of coniferous trees with a ratio of 20%–50% and 50%–80% is greater than that of coniferous trees with a ratio of 0%–20% and 80%–100%. There is no significant difference in fine root biomass and coarse root biomass under different mixing ratios. Secondly, the mixing ratio affects litter decomposition and nutrient conversion. Among the mixed forests with a ratio of 20%–50% and 50%–80% of coniferous trees, the decomposition amounts of C, N, P, Ca, and Mg in the litter fall are the highest. Additionally, there are differences in the relative abundance of soil microorganisms in the forest under different mixing ratios. When the proportion of coniferous trees is between 50% and 80%, the total number of bacteria and the total number of specific genes are the highest, and the distribution of microorganisms is uniform. The factors significantly related to the relative abundance of microorganisms in soil include litter volume, water capacity, annual decomposition rate, dead fine root volume, soil bulk density, water content, nutrients, and N/P. There are still shortcomings in the research. The research reveals the impact process between vegetation and soil. Further research is needed on the synergistic restoration mechanism of plant communities, soil, and microorganisms in limestone mountain forests. This research data serves as a reference for future research on dynamic processes.

Funding

The research is supported by Natural Science Research in Anhui Colleges and Universities Major Projects, (No.KJ2021A0160); Anhui Province Key Research and Development Plan Project, (No.202204c06020062); Anhui Province College Student Innovation and Entrepreneurship Project, (No.S202110879221, No. S202210879144).

References

Almasi, F. Organic Fertilizer Effects on Morphological and Biochemical Traits and Yield in Coriander (*Coriandrum sativum* L.) as an Industrial and Medicinal Plant. Agrotechniques in Industrial Crops, 2021; 1 (1): 19-23. https://doi.org/10.22126/etic.2021.6476.1011

Arji I, Karimpour Kalehjoobi S, Nejatian MA, Upadhyay TK. (2022). Yield and Yield Components of Grapevines as Influenced by Mixed Nano Chelated Fertilizer, Humic Acid and Chemical Fertilizers. Agrotechniques in Industrial Crops 2 (3): 156-165. https://doi.org/10.22126/atic.2023.8478.1076

Arji I, Safari M, Hadavi I. (2021). Effects of Different Organic Manures and Chemical Fertilizers on Yield and Yield Component of Olive (Olea europaea L.,) cv Zard in Kermanshah Province. Agrotechniques in Industrial Crops 1 (2): 61-70. https://doi.org/10.22126/atic.2021.6514.1013

Bergeron Y, Chen HYH, Kenkel NC, Leduc AL, Macdonald SE. (2014). Boreal mixedwood stand dynamics: Ecological processes underlying multiple pathways. The Forestry Chronicle 90: 202-213. https://doi.org/10.5558/tfc2014-039

BoseAK, WeiskittelA, Robert G W, Kuehne C, Michalet R. (2016). Assessing the factors influencing natural regeneration patterns in the diverse, multi-cohort, and managed forests of Maine, USA. Journal of Vegetation Science 27. https://doi.org/10.1111/jvs.12433

ChenYM, Cao Y. (2014). Response of tree regeneration and understory plant species diversity to stand density in mature Pinus tabulaeformis plantations in the hilly area of the Loess Plateau, China. Ecological Engineering 73: 238-245. https://doi.org/ 10.1016/j.ecoleng.2014.09.055

Feng YH, Schmid B, Loreau M, Forrester DI, Fei SL et al. (2022). Multispecies forest plantations outyield monocultures across a broad range of conditions. Science 376: 865-868. https://doi.org/10.1126/science.abm6363

Fritschie KJ, Cardinale BJ, Alexandrou MA, Oakley TH. (2014). Evolutionary history and the strength of species interactions: testing the phylogenetic limiting similarity hypothesis. Ecology 95: 1407-1417. https://doi.org/10.1890/13-0986.1

Fu B, Chen L, Ma K, Zhou H, Wang J. (2000). The relationships between land use and soil conditions in the hilly area of the loess plateau in northern Shaanxi, China. Catena 39: 69-78. https://doi.org/10.1016/S0341-8162(99)00084-3

Fu SL, Bell FW, Chen HYH. Long-term effects of intensive silvicultural practices on productivity, composition, and structure of northern temperate and boreal plantations in Ontario, Canada. Forest ecology and management 241: 115-126. https://doi.org/10.1016/j.foreco.2007.01.032

Ganjali S, Khajeh H, Gholami Z, Jomeh-ghasemabadi Z, Fazeli-Nasab B. (2022). Evaluation of Dormancy Failure Datura stramonium Plant Seeds under the Influence of Different Treatments Agrotechniques in Industrial Crops 2 (1): 32-41. https://doi.org/10.22126/atic.2022.7656.1049

Gholami R, Fahadi Hoveizeh N, Zahedi SM, Gholami H, Carillo P. (2023). The Efficacy of Melatonin on Flower Characteristics and Fruit Formation in Some Olive Cultivars Exposed to Low Irrigation. Agrotechniques in Industrial Crops 3 (2): 60-66. https://doi.org/10.22126/atic.2023.9015.1092

Gholami R, Pirkhezri M, Gerdakaneh M, Zahedi SM. (2022). Study of Lands Covered by Border Rivers of Kermanshah Province to Present the Pattern of Industrial Fruit Trees Cultivation. Agrotechniques in Industrial Crops 2 (4): 207-212. https://doi.org/10.22126/atic.2023.8619.1079

Hedwall PO, Skoglund J, Linder S. (2015). Interactions with successional stage and nutrient status determines the life-form-specific effects of increased soil temperature on boreal forest floor vegetation. Ecology and Evolution 5: 948-60. https://doi.org/ 10.1002/ece3.1412

Hernández-Clemente R, Cerrillo RMN, Hernández-Bermejo JE, Royo SE, Kasimis NA. (2009). Analysis of postfire vegetation dynamics of Mediterranean shrub species based on terrestrial and NDVI data. Environmental management. 43: 876-887. https://doi.org/ 10.1007/s00267-008-9260-x

Hosseini Beryekhani, SA, Parsa Z. (2021). A Review of the Effects of Using Municipal Treated Wastewater on Some Characteristics of Cotton Plants and Soil of Irrigated Fields. Agrotechniques in Industrial Crops, 2021; 1 (4): 182-187. https://doi.org/10.22126/atic.2022.7297.1035

Jalilian S, Mondani F, Fatemi A, Bagheri A.(2022). Evaluating the Effect of Farmyard Manure and Green Manure on Soil Physicochemical Traits and Growth Yield of Organic Sesame (*Sesamum indicium* L.). Agrotechniques in Industrial Crops 2 (1): 19-31. https://doi.org/10.22126/atic.2022.7332.1039

Kalacska M, Sanchez-Azofeifa GA, Rivard B, Caelli T, White HP et al. (2007). Ecological fingerprinting of ecosystem succession: Estimating secondary tropical dry forest structure and diversity using imaging spectroscopy. Remote Sensing of Environment 108: 82-96. https://doi.org/ 10.1016/j.rse.2006.11.007

Kardol P, Wardle DA. (2010). How understanding aboveground-belowground linkages can assist restoration ecology. Trends in ecology & evolution25: 670-679. https://doi.org/10.1016/j.tree.2010.09.001

Maisto G, De Marco AD, Meola A, Sessa L, Santo AVD.(2011). Nutrient dynamics in litter mixtures of four Mediterranean maquis species decomposing in situ. Soil Biology and Biochemistry 43: 520-530. https://doi.org/10.1016/j.soilbio.2010.11.017.

Moreno-Gutiîerrez C, Battipaglia G, Cherubini P, Delgado HA, Ignacio QJ. (2015). Pine afforestation decreases the long-term performance of understorey shrubs in a semi-arid Mediterranean ecosystem: a stable isotope approach. Functional Ecology 29: 15-25. https://doi.org/10.1111/1365-2435.12311

Nowroz F, Roy T, Haque M, Ferdous J, Noor R et al. (2021) Yield and Grading of Potato (*Solanum tuberosum* L.) as Influenced by Different Mulch Materials. Agrotechniques in Industrial Crops 1 (1): 1-10. https://doi.org/10.22126/etic.2021.6209.1001

Omidmehr Z. (2022). Evaluation the Effect of Conservation Tillage on Sunflower Yield and Energy Productivity. Agrotechniques in Industrial Crops 2 (2): 74-78. https://doi.org/10.22126/atic.2022.7668.1050

Paredes D, Cayuela L, Gurr GM, Campos M. (2015). Single best species or natural enemy assemblages? a correlational approach to investigating ecosystem function. BioControl 60: 37-45. https://doi.org/ 10.1007/s10526-014-9620-9

Paydar Z, Chen Y. (2014). Water cycle and irrigation expansion: an application of multi-criteria evaluation in the limestone coast (Australia). Journal of Water Resource and Protection 6: 655-668. https://doi.org/10.4236/jwarp.2014.67063

Penny GG, Daniels KE, Thompson SE. (2013). Local properties of patterned vegetation: quantifying endogenous and exogenous effects. Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences 4: 371 (2004). https://doi.org/10.1098/RSTA.2012.0359

Pocock MJO, Evans DM, Memmott J. (2012). The robustness and restoration of a network of ecological networks. Science 335: 973-977. https://doi.org/ 10.1126/science.1214915

Prescott CE, Zabek LM, Staley CL, Kabzems R. (2000). Decomposition of broadleaf and needle litter in forests of British Columbia: influences of litter type, forest type, and litter mixtures. Canadian Journal of Forest Research 30: 1742-1750. https://doi.org/ 10.1139/cjfr-30-11-1742

Ratke RF, Pereira HS, dos Santos JDG, Frazo JJ, Dias BDO. (2014). Root growth, nutrition and yield of maize with applied different limestone particle size in the Cerrado soil. American Journal of Plant Sciences 5: 463-472. https://doi.org/10.4236/ajps.2014.54060

Rheault G, Proulx R, Bonin L. (2015). Plant species richness prolongs the growing season of freely assembled riparian herbaceous communities under dry climatic conditions. Agriculture. Ecosystems & Environment 200: 71-78. https://doi.org/10.1016/j.agee.2014.11.007

Salehi Sardoei A, Babarabi M, Ghasemi H. (2023). Vermicompost as Growing Media Replacement for *Polianthes tuberosa* var Pearl Production. Agrotechniques in Industrial Crops 3 (1): 44-52. doi: 10.22126/atic.2023.9121.1096

Schafer A, Man R, Chen HYH, Lu P. (2014). Effects of post-windthrow management interventions on understory plant communities in aspen-dominated boreal forests. Forest Ecology and Management 323: 39-46. https://doi.org/10.1016/j.foreco.2014.03.030

Sun LY, Yang FT, Wang JY, Fang HY, Qi JY. (2015). Impacts of forest types on soil C, N and DOC loss in runoff in the laterite hilly region of southern China. Environmental Earth Sciences 74: 1391-1402. https://doi.org/10.1007/s12665-015-4129-9

Yazdanpanah-Ravari S, Heidari Sharifabad H, Abbaspour H, Iranbakhsh A. (2022) Investigation of the Effect of Arsenic Pollution in the Soil of Some Regions of Kerman on Physiological Characteristics of Pistacia atlantica L. and Medicago sativa L.. Agrotechniques in Industrial Crops 2 (3): 140-155. https://doi.org/10.22126/atic.2022.8289.1064

Zhang LF, Huang YY, Liu LP, Fu SL. (2013). Influences of species mixture on biomass of Masson pine (*Pinus massoniana* Lamb) forests. Genetics and Molecular Research 12: 3742-3749. https://doi.org/10.4238/2013.September.19.5

Zhou CY, Svensson BM, Yan JH, Xun C, Li K. (2014). Ecological compensation: a key to sustainable development in the guizhou province karst region, southwest China. Open Journal of Forestry 4: 212-222.https://doi.org/10.4236/ojf.2014.43028