Chapter

Afforestation in Karst Area

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Abstract

In order to study the afforestation technology in rocky desertification area and provide guidance for the cultivation and management of artificial forest in the later stage, an experimental study was carried out on the artificial forest in National long term scientific research base for comprehensive control of rocky desertification in Wuling Mountain, Western Hunan Province. The experiences of afforestation, land preparation and forest management in this area were summarized. The result show that: 1. Through appropriate afforestation land preparation and forest management measures, the forest in rocky desertification area can be successfully restored. 2. Vegetation restoration in rocky desertification area has formed relatively healthy and stable multi tree species and multi-level forest communities. 3. The biological yield of each afforestation tree species was significantly different with different tree species. 4. The diversity index and evenness index of undergrowth plants in different stands were significantly different. 5. Young trees of dominant species dominated the undergrowth vegetation of different stands, and the natural regeneration of each stand has been stabilized. 6. There are some differences in soil chemical properties under different stands. There were significant differences in SOM, TN, NO3-N, NH4-N and AP contents in the soil of the eight stands.

Keywords: karst area, afforestation, site preparation, growth pattern, biodiversity

1. Introduction

Rocky desertification land is one of the difficult forestation areas faced by human beings. 12% of the world's land is facing the problem of rocky desertification. The area of rocky desertification in China is 50 million ha. From Sinian to Triassic, the underlying strata deposited thick carbonate rocks, which laid the material foundation for the formation of rocky desertification in this area. Early studies have shown that the species diversity of vegetation communities will gradually increase with the improvement of environmental conditions and the development of succession stages and the community structure will become better and better (see [1]). The karst area has strong spatial heterogeneity, poor anti-interference ability, low ecosystem function, and very fragile environment. In addition, it is affected by backward productivity and unreasonable human activities. Vegetation is gradually degraded, vegetation coverage is reduced, and the ability of soil to retain water and soil is reduced. It restricts the growth of plants, makes soil erosion present a vicious circle, and slows down the process of ecological civilization construction in karst areas (see [2, 3]).

Xiangxi Autonomous Prefecture is located in the hinterland of Wuling Mountain, with a forest area of 633,200 hectares and a forest coverage rate of 61%. The territory is rich in biological species resources, with many rare species, which can be called a natural treasure house of wild animal and plant resources and a gene bank of biological species. 19 species of world-famous relict plants such as *Cyclops*, *Metasequoia*, *Davidia involucrata*, *Ginkgo biloba*, *Gastrodia*, *camphor*, and *turmeric* are preserved; more than 230 species of oily plants with seed oil content greater than 10%; 216 ornamental plants in 91 families 383 species; There are more than 60 kinds of vitamin plants; 12 kinds of pigment plants. It is the main producing area of *Tung Oil, Camellia oleifera, lacquer* and Chinese medicinal materials, especially in the prefecture, there is the most complete and largest low-altitude evergreen broad-leaved primary secondary forest in the subtropical zone. In the past thousand years, the forests in this area were cut down and the hillsides were used for farming. As a result, the soil erosion in this area was accelerated and the rocky desertification was intensified. Vegetation restoration is the key to ecological reconstruction, and the restoration of plant diversity is an important part of vegetation restoration. The zonality and succession of vegetation should be followed by the selection of suitable economic tree species, and the optimal allocation of forest should have configured shrub and grass. Therefore, it is of great significance to explore the technology of forest vegetation restoration in rocky desertification area, and Vigorously promote the use of rocky desertification management models based on locally suitable native tree species, continue to increase comprehensive conservation efforts, and ultimately create a near-natural growth community environment for vegetation growth, so as to achieve the expected results of rocky desertification vegetation restoration.

The purpose of this study is to restore the near natural forest ecosystem with multi tree species and multi canopy in the rocky desertification area with serious vegetation degradation through silviculture. This experimental study preliminarily achieved the goal, improved the soil production capacity, reduced soil erosion, improved the microclimate of afforestation in rocky desertification area, produced a certain amount of wood, and it has improved the living environment, also increases the income of the people in the area. This effort caused the social production activities into a sustainable virtuous circle.

2. Materials and methods

2.1 Overview of the study area

Under the influence of subtropical monsoon and mountain control, the national long-term scientific research base of Wuling Mountain has obvious Subtropical monsoon climate characteristics. The four seasons are distinct, the precipitation is abundant. The annual average sunshine hours are 1240-1440 h, the annual average temperature is 15.8–16.9°C, the annual active accumulated temperature is 4835–5200°C, the frost free period is 269–292 days, and the annual average rainfall is 1300–1500 mm.

Since 1964, the local forestry department has carried out the artificial afforestation movement on the mountain with serious rocky desertification. After 55 years of hard work, 126 native tree species of 39 families and more than 10 exotic tree species have been successfully used to carry out forest vegetation restoration test on 386.7$hm^2$of serious rocky desertification mountain. Here, from the past chaotic rock slope with overgrown weeds, it has become today's lush and green mountains Linhai has formed a modern forestry construction demonstration base integrating forest management and forestry scientific research in rocky desertification areas.

The national long-term scientific research base for comprehensive management of rocky desertification in Wuling Mountain is selected as the research object. The research base is located in Qingping Town, Yongshun County, Xiangxi Autonomous Prefecture, Hunan Province, 110° 13′40.296 "E, 29 ° 3'21.59"N, belonging to the

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central area of Wuling Mountain Area. The highest altitude is 820 meters and the lowest altitude is 320 meters (**Figures 1** and **2**).

The parent rock is limestone, which belongs to severe rocky desertification area. There are three main methods of land preparation in this area:

a. The artificial trench is suitable for sites with more than 90% rock exposure.

b. The artificial bund is suitable for slope land with less than 90% rock exposure.

c. Cave shaped site preparation is suitable for the site of stone bud pile.

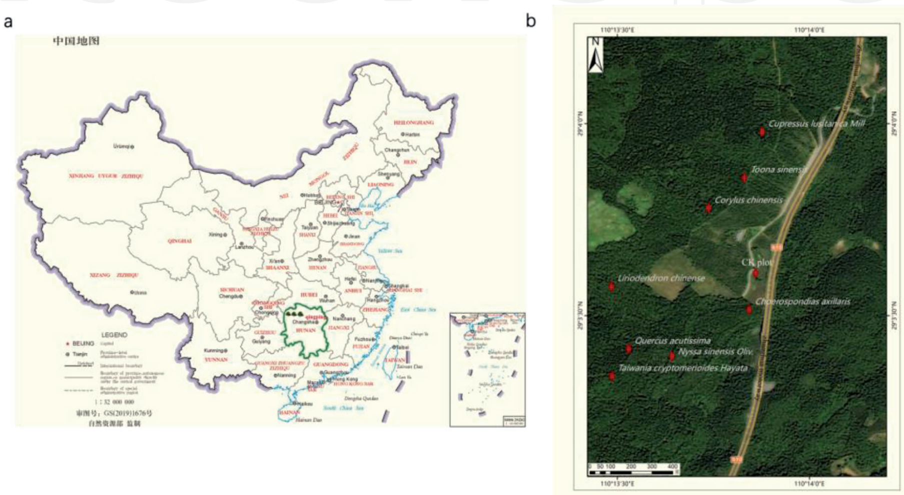

Figure 1.
Research location; a. Research location in China b. The plot distribution map.

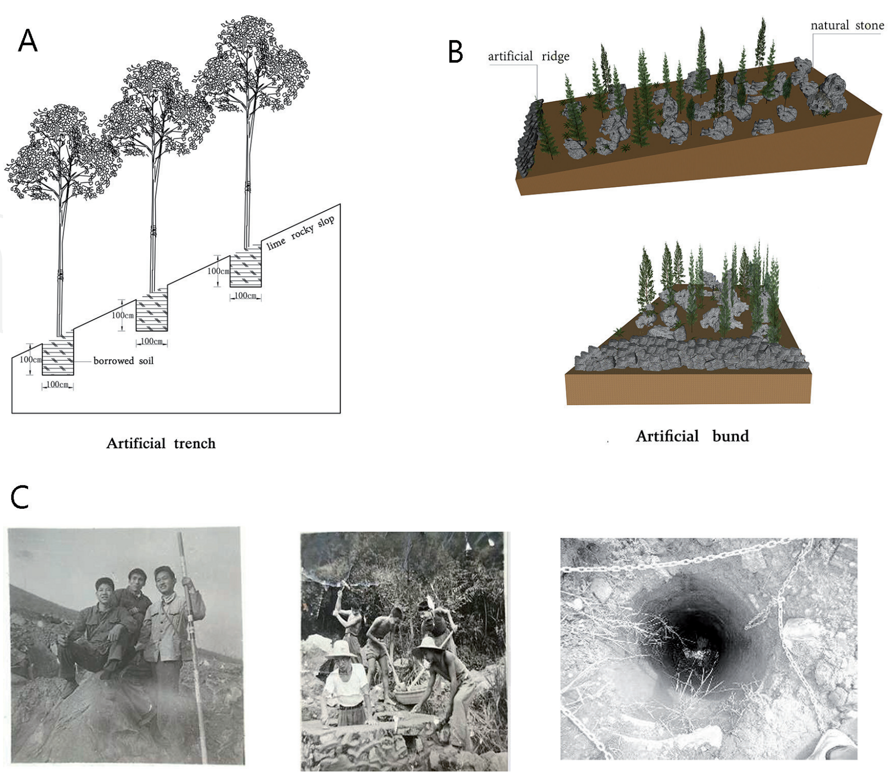

Figure 2.
Land preparation; A. The level artificial trench B. The level artificial bund C. The local forestry workers carried out land cave-shaped soil preparation in 1973.

Plot name	Afforestation patterns	Plot area/m^2	Canopy closure	Stand age/a	Percentage of total forest area/%
Cupressus lusitanica (Mill.)	Pure forest	20 m*30 m	0.68	25	3%
Taiwania cryptomerioides (Hayata.)	Pure forest	20 m*30 m	0.7	40	5%
Quercus acutissima (Carruth.)	Pure forest	20 m*30 m	0.69	20	4%
Corylus chinensis (Franch.)	Pure forest	20 m*30 m	0.8	42	2%
Toona sinensis (Juss.)	Pure forest	20 m*30 m	0.82	40	5%
Nyssa sinensis (Oliver.)	Pure forest	20 m*30 m	0.65	40	3%
Liriodendron chinensis (Sarg.)	Pure forest	20 m*30 m	0.67	37	8%
Choerospondias axillaris (Roxb.)	Pure forest	20 m*30 m	0.77	35	5%

Table 1.
The basic situation of monitoring sample plots.

In terms of tree species selection, afforestation mode and stand tending management, the selection principle of tree species follows the principle of local tree species and suitable tree species, and In order to increase local species resources and land biodiversity, a small number of exotic species are introduced. For example, *Liriodendron chinense* (Hemsl.) Sarg. All the afforestation methods are seedling planting. Young forest tending combined with crop interplanting was used to loosen soil and weed. In the early stage of afforestation, Corn was the main crop in early interplanting, After the stand was closed, crop interplanting was stopped, and the stand density was adjusted by artificial pruning and thinning.

2.2 Experimental design

The fixed standard plot survey method was adopted in January 2019. In the study area, eight representative native precious tree species were selected: *Toona sinensis* (Juss.), *Choerospondias axillaris* (Roxb.), *Corylus chinensis* (Franch.), *Taiwania cryptomerioides* (Hayata), *Cupressus lusitanica* (Mill.), *Nyssa sinensis* (Oliver.) and *Liriodendron chinensis* (Sarg.). One is unplanted shrub and grassland as a control plot, Three20 m * 30 m sample plots were set up for each stand. The DBH, tree height, height of the beginning of the crown, crown diameter and stem straightness were recorded, and the average tree height and DBH were calculated. Calculation of average DBH and average tree height of sample plot: the average DBH of sample plot is the DBH corresponding to the average cross-sectional area, so the cross-sectional area of each tree should be calculated, and then the average cross-sectional area should be calculated to calculate the average DBH. The average tree height is to find out the corresponding tree height with the average DBH on the basis of the DBH tree height curve. The basic conditions of the monitored plots are shown in **Table 1**.

3. Research contents

Eight artificial forests were selected for the study. The main research contents are as follows:

3.1 Growth patterns of plantation

Each tree was investigated in the sample plot, and one standard tree was selected for stem analysis in each standard plot. Through the measurement of DBH, tree height and volume growth process, the measured data were obtained, and the total growth, annual growth and average growth curve of each tree species were drawn to analyze their growth pattern.

3.2 Biodiversity of plantation

Three 2 m * 2 m shrub plots were set up in 8 fixed sample plots of *Toona sinensis* (Juss.), *Choerospondias axillaris* (Roxb.), *Corylus chinensis* (Franch.), *Taiwania cryptomerioides* (Hayata), *Cupressus lusitanica* (Mill.), *Nyssa sinensis* (Oliver.) and *Liriodendron chinensis* (Sarg.). Three 1 m × 1 m small plots were set up to investigate the shrub and grass diversity under the forest.

3.3 Biomass survey of tree layer in plantation

The biomass of standard wood was measured by stratified harvest method. 500 g samples were taken from the upper, middle and lower layers of branches and stem. The underground part was excavated in three layers of 0–20 cm, 20–40 cm and 40–60 cm within the radius range of 1 m of sample tree, and were divided into coarse roots (d > 5) three levels of roots (5 cm > d > 1 cm), medium root (5 cm > d > 1 cm) and fine root (d < 1 cm) were placed by classification, and 500 g samples of their fresh weights were weighed. The fresh weights of leaves, stem, bark and roots were measured, and then dried in 85°C oven to constant weight. The water content of each part and the biomass of standard tree were calculated, and the biomass of the whole tree layer was calculated. Calculate the dry mass of each component, calculate the dry mass of the sample wood, and then convert the dry mass per unit area and stand biomass.

3.4 Regeneration patterns of plantation

The ground diameter, DBH, tree height, crown diameter and stem straightness of all young trees in the plot were recorded, and the average tree height and DBH were calculated.

3.5 Soil sampling and analysis

The soil physical properties were mainly measured for *Taiwania cryptomerioides* (Hayata.), *Liriodendron chinensis* (Sarg.), and *Taiwania cryptomerioides-Liriodendron chinensis* mixed forest, and soil nutrients were measured for eight forests. Three 20 m* 20 m sample plots were selected as the sample plots in the fixed sample plots, and the soil samples were randomly selected from three points in each sample plot. The visible animal and plant residues and small stones were carefully removed, and then were mixed evenly through a 2 mm sieve. The samples were taken back to the laboratory for analysis. The rocky desertification unforested shrub grassland was taken as the research sample plot, and each sample was determined three times.

Soil samples were dried by natural air to remove impurities. 5-10 g samples were screened by 2 mm soil sieve to determine the contents of C, N and P in soil. Soil C was determined by potassium dichromate external heating sulfuric acid oxidation method (LY / T 1237–1999), while soil N and P were determined by semi micro Kjeldahl method (LY / T 1228–1999) and molybdenum antimony resistance Colorimetry (LY/ T 1232–1999) (see [4]).

3.6 Statistical analyses

3.6.1 Species diversity calculation method

1. The calculation formula of species importance value is as follows:

Important value = (relative density + relative dominance + relative frequency)/3 × 100% (see [5]).

2. Species diversity calculation method

$$\text{Berger} - \text{Parker index}: \text{d} = \text{Nmax} / \text{N}$$

$$\text{Simpson index}: \text{D} = 1 - \sum\{ni(ni-1)/[\text{N}(\text{N}-1)]\}$$

$$\text{Shannon} - \text{wiener index}: \text{H} = -\sum_{i=1}^{s} pi \ln pi$$

$$\text{Pielou index}: \text{P} = \frac{H}{\ln S}$$

Note: In the formula, N_{max} is the number of individuals of the most dominant species; N is the total number of individuals; ni is the number of individuals of the i-th species. Pi is the ratio of the number of individuals of the i-th species to the number of individuals of all species in the community; S is the total number of species in the community (see [6]).

3.6.2 Calculation method of stand average DBH

1. Quadratic mean diameter at breast height

The quadratic mean diameter at breast height of the stand is calculated based on the section area of the stand height at breast height, as follows: $D_g = \sqrt{\frac{1}{n}\sum_{i=1}^{n} d_i^2}$

Dg——Stand quadratic mean diameter at breast height
di——Diameter at breast height of the i-th tree
n——Total number of trees in the plot

2. Average stand height

The average height of forest stands adopts the weighted average height of section area, and the calculation formula is: $\bar{H} = \frac{\sum_{i=1}^{k} \bar{h}_i G_i}{\sum_{i=1}^{k} G_i}$

$\bar{H}$ —— Average stand height
$\bar{h}_i$ —— The arithmetic average height of the i-th diameter tree in the forest stand
$\overline{G_i}$ —— The cross-sectional area of the breast height of the i-th diameter forest tree in the stand
k——Number of stand diameter steps

3. Volume per plant

The volume per plant is calculated using the average stem profile. The specific calculation formula is as follows: $V_{average} = g_{1.3}(h+3) \times f_c \times 667$

$V_{average}$——Average forest accumulation per m^2
fc——Average form factor
$g_{1.3}$——Average wood breast height section area
h——Average tree height

3.6.3 Data analysis

Use Excel to calculate the standard tree's height (H(t)), diameter at breast height(D(t)), and volume per plant(V(t)), volume average growth ($V_\theta(t)$), volume annual growth ($V_Z(t)$), etc. Statistical analysis was performed with SPSS25.0 (see [7]), single-factor analysis of variance was used to test the significant differences in soil physical and chemical properties of different forest stands, and Pearson correlation was used to study the correlation between plant community diversity and soil nutrients; origin8.0 was used for mapping.

4. Results and analysis

4.1 Growth patterns of different plantations

4.1.1 The growth pattern of plantation tree height

According to the survey data of fixed sample plots, the age variation curve of tree height was drawn. The height and growth of each tree species increase with age (**Figure 3**), but the rapid growth period of each tree species is different. The specific performance is as follows: *Taiwania cryptomerioides* 1 ~ 15 years is the fast-growth period, and the growth rate gradually slows down after 15 years, and the tree height growth reaches 19.7 m at 40 years; *Quercus acutissima* 1 ~ 2 years is the fast-growth period, and the growth rate gradually slows down after 2 years. The height growth

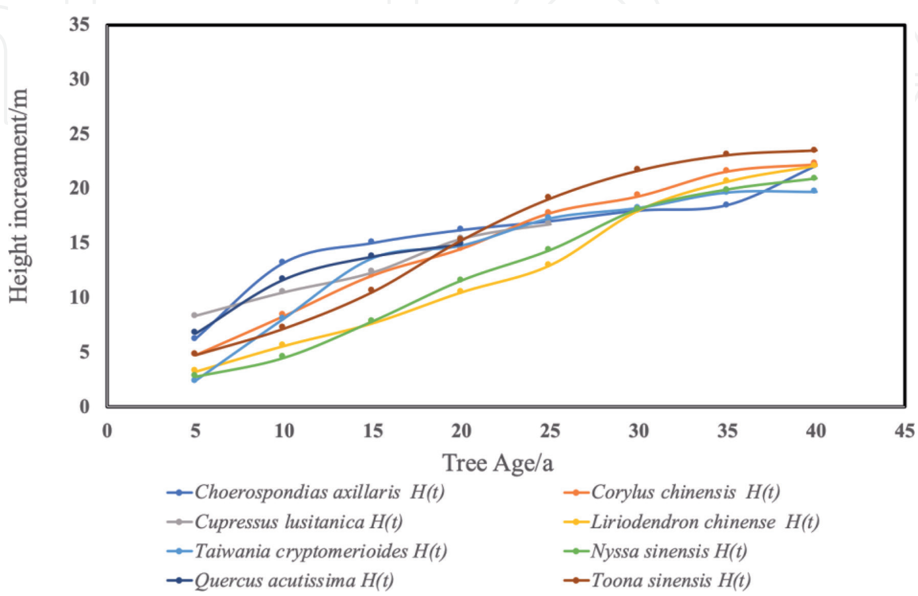

Figure 3.
Height growth curve.

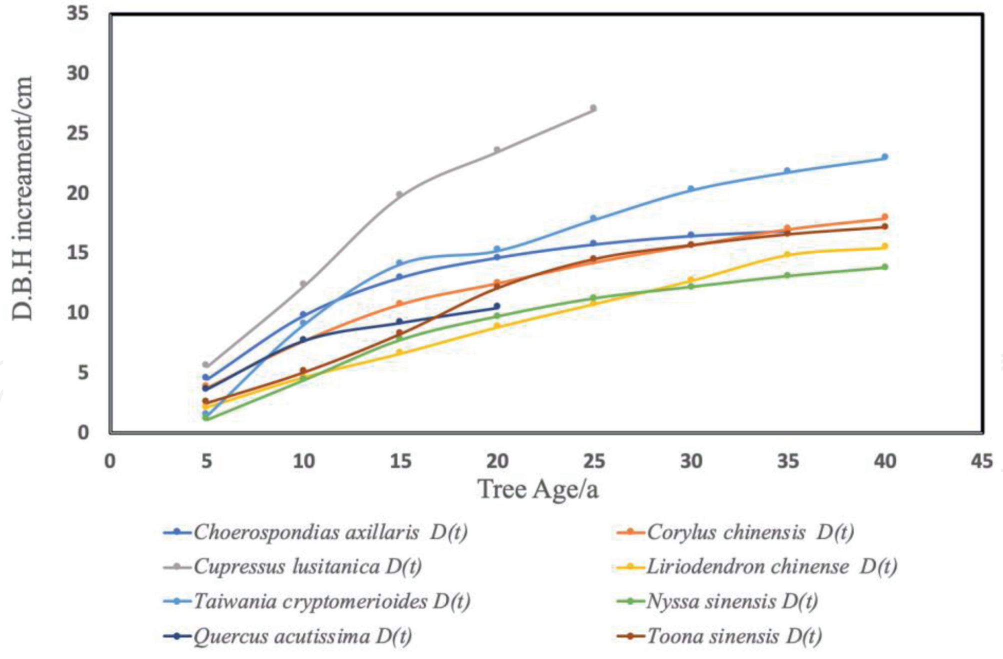

Figure 4.
DBH growth curve.

reaches 14.9 m; *Cupressus lusitanica* 1 ~ 4a is the fast growth period, the growth rate gradually slows down after 15 years, and the tree height growth reaches 16.8 m at 24 years (**Figure 4**). *Corylus chinensis* 1 ~ 27 years is the fast-growing period. After 27 years, the growth rate gradually slows down. After 37 years, the height of the tree grows extremely slowly, and the height of the tree reaches 22.3 m at 42 years. For *Choerospondias axillaris*,1-10a is the fast-growing period, and the growth rate gradually slows down after 10a, and the tree height grows to 18.5 m at 35 years. *Toona sinensis* 1 ~ 35 years is the fast-growing period. After 35 years, the growth rate gradually slows down, and the tree height grows to 23.5 m at 40 years. *Nyssa sinensis* 1–30 years is the fast-growing period, the growth rate gradually slows down after 30a, and the tree height growth reaches 20.9 m at 40 years. *Liriodendron chinensis* 1 to 27 years is a fast-growing period, after 27 years, the growth rate gradually slows down, and the tree height grows to 22.1 m at 37 years.

4.1.2 Growth pattern of diameter at breast height of plantation

The growth of diameter at breast height of each tree species increases with age. Specifically, it shows that: the first 1–5 years after planting of *Taiwania cryptomerioides* grows slowly, the growth enters the fast growth period after 5 years, the growth of diameter at breast height begins to slow down after 15 years, and the growth of diameter at breast height reaches 23 cm at the 40th year; the rapid growth period after the plantation of *Cupressus lusitanica*, The growth slowed down after 14th year, and the breast diameter growth reached 27 cm at 24th year. After afforestation, *Corylus chinensis* entered the fast-growing period, and the growth slowed down after 17 years, and the diameter at breast height reached 17.9 cm at 42 years; *Choerospondias axillaris* quickly entered the fast-growing period after afforestation, the growth slowed down after 15 years, and the diameter at breast height reached 16.8 cm at 35 years. *Toona sinensis* grows slowly in the first 5 years after afforestation. After a slow growth period, it enters the fast-growth period after 5 years and slows down after 25 years. The diameter at breast height reaches 17.2 cm at 40th year. *Nyssa sinensis* grow slowly in the first 5 years after afforestation. After a slow growth period, they enter the fast-growth period after 5 years, and the growth slows down after 25 years. The diameter at breast height reaches 13.8 cm at 40th year. After afforestation, the first 2 years of *Liriodendron chinensis* grows slowly. After the slow growth stage, it enters the fast growth stage after 2 years. The growth slows down after 32 years. The diameter at breast height reaches 15.5 cm at 37 years.

4.1.3 Volume growth pattern of plantation forest

It can be seen from **Figure 5** that the volume growth of each tree species increases with age. Specifically, it shows that *Nyssa sinensis* go through the first 10 years of slow growth period after afforestation, and then enter the fast growth period after 10 years, and the volume growth reaches 0.1476m^3 at 40th year. Its volume annual growth $V_Z(t)$ reached its maximum value of 0.0037m^3 at $V_Q(t)$ at 40th year. In the first 2 years of *Liriodendron chinensis*, the forest was in a slow growth period, and after 2 years, it entered the rapid growth period. At 37th year, the volume growth reached 0.2004 m^3. The continuous annual growth of the volume $V_Z(t)$ reached the maximum value of 0.01344 m^3 at 32th year, and the average growth volume reached the maximum value of 0.00542 m^3 at $V_Q(t)$ at 37th year. *Quercus acutissima* was in a slow growth period 5 years ago, and entered a fast growth period 5 years later, and the volume growth reached 0.0814m^3 at 17th year. The volume of continuous annual growth $V_Z(t)$ reached the maximum value of 0.0083 m^3 at 17th year, and the average growth volume reached the maximum value of 0.0048 m^3 at $V_Q(t)$ at 17th year. *Cupressus lusitanica* was in the slow growth period 4 years ago, and entered the fast growth period after 4 years. The volume growth reached 0.3749 m^3 at 24th year. The continuous annual growth volume $V_Z(t)$ of *Cupressus lusitanica* reached the maximum value of 0.0264 m^3 at 24th year, and the average growth volume reached the maximum value of 0.0156 m^3 at $V_Q(t)$ at 24th year; none of the four tree species has reached quantitative maturity and theoretically the optimal cutting age.

After afforestation, the growth of *Toona sinensis* growth slowly in the first 10 years, then growth accelerated to 40 years of volume growth reached 0.2540 m^3. The annual volume growth of *Toona sinensis* reached the maximum value of 0.0120 m^3 at 25th year, and the average growth $V_Q(t)$ reached the maximum value of 0.0061m^3 at 40th year. V_Z (t) and $V_Q(t)$ intersected at the 39th year, when *Toona sinensis* reached the best cutting age. After afforestation, the growth rate of *Choerospondias axillaris* was slow in the first five years, and entered the fast-growing stage after five years. The volume growth reached 0.1868 m^3 in 35 years. The annual volume growth of *Choerospondias axillaris* reached the maximum

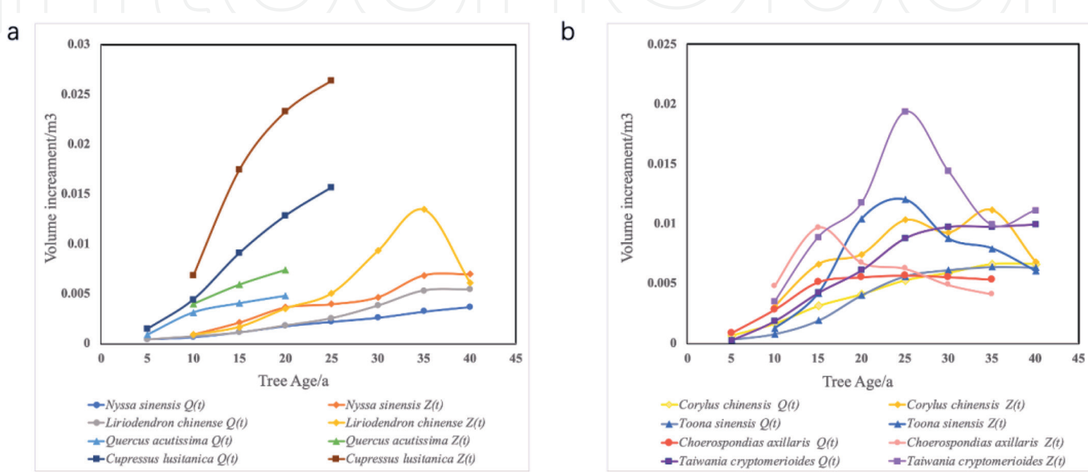

Figure 5.
Volume growth curve; a. The continuous annual growth volume $V_Z(t)$ of plantation forest; b. The average growth volume $V_Q(t)$ of plantation forest.

value of 0.0097 m^3 at 20 years, and the average growth reached the maximum value of 0.0057 m^3 when $V_Q(t)$ was 25 years. $V_Z(t)$ and $V_Q(t)$ intersect at 27th year, which is the best cutting age of *Choerospondias axillaris*. After afforestation, the growth of *Corylus chinensis* was slow in the first seven years, and entered the fast-growing stage after seven years. The volume growth reached 0.2783m^3 at 42th year. The annual volume growth of *Corylus chinensis* reached the maximum value of 0.0112 m^3 at 37 years, and the average growth reached the maximum value of 0.0068 m^3 when $V_Q(t)$ was 42 years. $V_Z(t)$ and $V_Q(t)$ intersect, and the best cutting age at 42th year. After afforestation, *Taiwania cryptomenoides* experienced slow growth period in the first 10 years, and entered the fast-growing stage after 10 years, and the volume growth reached 0.3959 m^3 at 40 years. V_Z (t) reaches the maximum value of 0.0194 m^3 at 25th year and 0.0099m^3 at $V_Q(t)$ 40th year. $V_Z(t)$ and $V_Q(t)$ do not intersect before 40th year. Therefore, the best cutting age of *Taiwania cryptomenoides* is at least 40th year.

4.2 Biomass per tree and its distribution

The biomass of individual tree was significantly different with different tree species (**Table 2**). The order of biomass per plant of eight tree species was as follows: *Cupressus lusitanica* (382.483 kg/plant) > *Taiwania cryptomenoides* (239.907 kg/plant) > *Corylus chinensis* (205.245 kg /plant) > *Toona sinensis* (167.054 kg/ plant) > *Quercus acutissima* (149.734 kg/ plant) > *Choerospondias axillaris* (126.345 kg/ plant) > *Nyssa sinensis* (124.824 kg/ plant) > *Liriodendron chinensis* (117.456 kg/ plant). The results showed that the biomass of each component of tree species was as follows: stem > branches> roots of *Cupressus lusitanica* and *Taiwania cryptomenoides*; the biomass of *Corylus chinensis*, *Toona sinensis*, *Quercus acutissima*, *Choerospondias axillaris*, *Nyssa sinensis* and *Liriodendron chinensis* shows:Stem > roots> branches.

Tree species	Biomass per plant /(kg/plant)			
	Stem	Branches	Tree root	Total
Cupressus lusitanica	247.09	76.34	59.06	382.48
%	64.60	20.00	15.40	100.00
Taiwania cryptomenoides	154.68	49.47	35.75	239.91
%	64.50	20.60	14.90	100.00
Corylus chinensis	166.16	4.72	34.37	205.25
%	81.00	2.30	16.70	100.00
Toona sinensis	140.95	5.73	20.38	167.05
%	84.40	3.40	12.20	100.00
Quercus acutissima	111.9	17.15	20.69	149.73
%	74.70	11.50	13.80	100.00
Choerospondias axillaris	97.88	6.74	21.72	126.35
%	77.50	5.30	17.20	100.00
Nyssa sinensis	97.72	9.35	17.76	124.82
%	78.30	7.50	14.20	100.00
Liriodendron chinensis	93.02	4.38	20.06	117.46
%	79.20	3.70	17.10	100.00

Table 2.
Biomass comparison of different tree species.

4.3 Stand biomass and its distribution pattern

The biomass of individual tree is converted into stand biomass as shown in **Table 3**. The biomass of each stand is as follows: *Cupressus lusitanica* (319.171 t·ha^{-1}) > *Quercus acutissima* (281.197 t·ha^{-1}) > *Corylus chinensis* (210.264 t·ha^{-1}) > *Taiwania cryptomenoides* (186.601 t·ha^{-1}) > *Toona sinensis* (18 5.386 t·ha^{-1}) > *Choerospondias axillaris* (181.875 t·ha^{-1}) > *Liriodendron chinensis* (161.548 t·ha^{-1}) > Nyssa sinensis (158.32 t·ha^{-1}).The biomass of tree layer, understory vegetation layer and litter layer of different stands were compared and analyzed under the condition of similar forest age.

1. Tree layer: *Cupressus lusitanica* > *Quercus acutissima* > *Corylus chinensis* > *Toona sinensis* > *Taiwania cryptomenoides* > *Nyssa sinensis* > *Liriodendron chinensis* > *Choerospondias axillaris.*

2. Undergrowth vegetation layer: *Taiwania cryptomenoides* > Choerospondias axillaris > *Cupressus lusitanica* > *Corylus chinensis* > *Liriodendron chinensis* > *Toona sinensis* > *Quercus acutissima* > *Nyssa sinensis.*

3. Litter layer: *Corylus chinensis* > Nyssa sinensis > *Cupressus lusitanica* > *Taiwania cryptomenoides* > *Liriodendron chinensis* > *Toona sinensis* > *Quercus acutissima* > *Choerospondias axillaris*.

4. Total biomass:*Cupressus lusitanica* > *Quercus acutissima* > *Coryl*us chinensis > *Taiwania cryptomenoides* > *Toona sinensis* > *Nyssa sinensis* > *Liriodendron chinensis* > *Choerospondias axillaris.*

5. Tree layer > litter layer > understory vegetation layer

The results showed that: the total biomass of *Cupressus lusitanica* forest was the largest, the biomass of understory vegetation layer and litter layer was also higher than that of other forests, and the growth trend was better than that of other tree species. It can be seen that there are some problems in the regeneration of evergreen

Tree species	Age of forest /a	Stand biomass /t·ha^{-1}					
		Stem	Branch	Tree root	Undergrowth vegetation	Litter	Total
Cupressus lusitanica	25	201.79	62.34	48.23	2.65	4.16	319.17
Taiwania cryptomenoides	40	116.01	37.10	26.82	2.98	3.69	186.60
Quercus acutissima	20	207.02	31.72	38.27	1.71	2.48	281.20
Corylus chinensis	42	162.01	4.60	33.51	2.06	8.09	210.26
Toona sinensis	40	152.70	6.20	22.08	1.81	2.60	185.39
Nyssa sinensis	40	138.43	13.24	25.16	0.76	4.28	181.88
Liriodendron chinensis	37	124.02	5.84	26.75	1.94	3.00	161.55
Choerospondias axillaris	35	119.09	8.20	26.43	2.79	1.81	158.32

Table 3.
Stand biomass of different tree species.

broad-leaved trees, which need to be paid attention to. It is not our ultimate goal to build artificial pure forest. We need to use artificial afforestation technology to restore its ecological function, carry out natural regeneration, and finally form a complex and stable ecological community structure.

4.4 Differences of undergrowth plant diversity in different stands

Habitat heterogeneity and plant biological characteristics are the main factors affecting the diversity of understory plants (see [8]). The diversity index and evenness index of different plantations were significantly different (**Figure 6**), indicating that there were differences in the diversity level of understory plants in different plantations. The Berger Parker index of shrub layer in different stands was the largest in *Liriodendron chinensis*. The Simpson index of is the largest of *Corylus chinensis* forest, and that of *Cupressus lusitanica* is the smallest among 8 stands. For Shannon Wiener index, *Cupressus lusitanica* is the largest, *Liriodendron chinensis* is the smallest. The Berger Parker index of herbaceous layer in different stands was the largest in *Toona sinensis* forest and the smallest in *Taiwania cryptomenoides* forest; Simpson index of eight stands was the largest in *Taiwania cryptomenoides* forest and the smallest in *Quercus acutissima* forest. For Shannon Wiener index, *Nyssa sinensis* forest is the largest, *Taiwania cryptomenoides* forest is the smallest. The analysis of variance of undergrowth shrub and herb diversity in each stand shows that the diversity of undergrowth plants is significant, but there is no significant difference in Pielou index among the eight stands, indicating that the evenness of plants in the eight stands is basically similar. Secondly, the Shannon Wiener index of undergrowth shrub in *Cupressus lusitanica* was higher than that in other forest stands, indicating that the plant diversity under *Cupressus lusitanica* was richer than that in other stands, but the diversity index of shrub grassland without afforestation was higher than that of other stands ($P < 0.05$).

4.5 The regeneration difference of young trees in different stands

The horizontal spatial distribution of seedlings and young trees is often reflected by the spatial distribution pattern, which will change with the biological characteristics of plants and the comprehensive influence of environmental conditions (see [9]). There are many factors that affect the spatial distribution of seedlings and saplings, and the main factors are seed dispersal and different habitats (see [10]). It can be seen from **Table 4** that saplings of dominant species dominate the undergrowth vegetation of different stands. The regeneration of saplings under *Taiwania cryptomenoides* and *Toona sinensis* stands has gradually appeared other tree

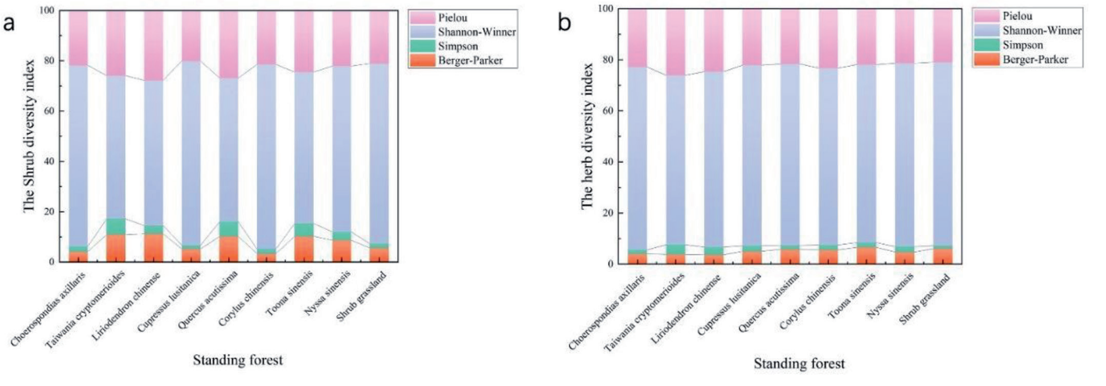

Figure 6.
Diversity index of understory plants; a. The shrub diversity index; b. The herb diversity index.

Sample plot	Seedling species	Tree height /m	DBH/cm	Average crown diameter /m
Choerospondias axillaris	*Choerospondias axillaris*	3.47 ± 1.21	3.15 ± 0.88	3.47 ± 2.81
	Cinnamomum camphora	4.32 ± 1.17	3.32 ± 0.75	4.35 ± 2.02
	Lindera communis	2.87 ± 0.06	1.93 ± 0.55	2.74 ± 0.61
Corylus chinensis	*Corylus chinensis*	1.73 ± 0.11	2.90 ± 0.28	36.5 ± 2.12
	Cinnamomum camphora	1.40 ± 0.14	2.11 ± 0.43	28.6 ± 20.67
Cupressus lusitanica	*Zanthoxylum bungeanum*	1.17 ± 0.32	33.2 ± 55.95	0.14 ± 0.19
	Camellia japonica	1.10 ± 0.83	18.22 ± 52.38	0.41 ± 0.65
	Cupressus lusitanica	2.40 ± 0.28	3.65 ± 0.21	0.09 ± 0.11
	Eriobotrya japonica	1.25 ± 0.35	0.65 ± 0.21	0.04 ± 0.00
	Rhus chinensis	1.55 ± 0.66	2.18 ± 2.07	0.09 ± 0.08
	Cinnamomum camphora	1.02 ± 0.6	1.43 ± 0.15	0.11 ± 0.08
	Liriodendron chinensis	1.27 ± 0.43	3.16 ± 1.81	0.03 ± 0.01
	Vernicia fordii	3.25 ± 0.21	9.95 ± 7.14	0.16 ± 0.00
Liriodendron chinensis	*Liriodendron chinensis*	6.21 ± 2.82	3.22 ± 1.10	0.97 ± 0.36
	Cinnamomum camphora	5.22 ± 2.36	3.02 ± 0.90	0.92 ± 0.32
Taiwania cryptomenoides	*Acer davidii*	6.68 ± 1.72	3.05 ± 0.56	2.77 ± 2.67
	Taiwania cryptomenoides	3.77 ± 1.10	3.19 ± 0.75	2.51 ± 0.89
	Vernicia fordii	4.81 ± 0.57	3.15 ± 0.49	3.24 ± 1.19
Nyssa sinensis	*Nyssa sinensis*	1.95 ± 0.82	2.07 ± 1.11	0.46 ± 0.28
	Phoebe bournei	1.48 ± 0.82	1.61 ± 0.82	0.37 ± 0.27
	Camellia japonica	1.15 ± 0.48	1.71 ± 0.66	0.56 ± 0.25
Quercus acutissima	*Quercus acutissima*	7.37 ± 3.32	3.63 ± 1.12	3.41 ± 1.84
	Taiwania cryptomenoides	2.51 ± 1.13	2.41 ± 1.43	0.75 ± 0.74
Toona sinensis	*Acer davidii*	4.25 ± 1.07	2.82 ± 0.52	2.88 ± 1.02
	Cinnamomum camphora	4.33 ± 1.73	3.35 ± 1.17	3.65 ± 3.61

Note: Mean ± standard error.

Table 4.
Relationship between tree growth and natural regeneration of young forest under the forest.

species, and the natural regeneration of each stand has become stable. The growth of undergrowth plants is closely related to the growth of trees. The composition and structural characteristics of understory plants are closely related to the internal environmental conditions of plantations. On the one hand, because the growth and management of plantation affect the soil, water, light intensity, temperature and humidity and other micro environmental conditions, the growth and development of understory plants is limited, which directly affects the species, coverage, biomass and diversity of understory plants. On the other hand, after nearly 40 years of development, the plantations in the study area have formed a relatively stable understory environment. The pattern of understory plants is mainly formed by natural competition, which fully reflects the advantages and disadvantages of internal environmental conditions of different artificial forests and the intermediate relationship of understory niche. Therefore, most of the plantations are shade tolerant plants with strong adaptability.

4.6 The difference of soil physical and chemical properties among different stands

Soil density and total porosity are not only the basic physical characteristics of forest soil, but also important indicators of soil and water conservation, which affect the growth and development of understory plants (see [11]). The soil physical properties of typical *Taiwania cryptomenoides* (coniferous forest), *Liriodendron chinensis* (broad-leaved forest) and *Taiwania cryptomenoides-Liriodendron chinensis* mixed forest (coniferous and broad-leaved forest) were determined (**Table 5**). The average soil density in 0 ~ 30 cm depth soil layer was as follows: *Taiwania cryptomenoides* > *Liriodendron chinensis* > mixed forest > shrub grassland (CK)Plot.

In the depth of 0 ~ 30 cm, the average soil porosity was mixed forest (*Taiwania cryptomenoides- Liriodendron chinensis*) > shrub grassland > *Taiwania cryptomenoides* pure forest >*Liriodendron chinensis* pure forest. The soil density in 0–15 cm and 15–30 cm soil layers of the shrub grassland was significantly lower than that of the pure *Taiwania cryptomenoides* forest ($P \leq 0.05$), but there was no significant difference in soil density between the mixed forest of *Taiwania cryptomenoides* and pure forest. The soil density of each stand decreased with the increase of soil depth. The soil total porosity of different stands increased with the increase of soil depth, and with the increase of soil layer, the soil porosity of different stands showed significant difference. On the whole, the soil water holding capacity of the mixed forest of *Taiwania cryptomenoides* and *Liriodendron chinensis* was higher than that of pure *Taiwania cryptomenoides* and pure *Liriodendron chinensis*. Compared with pure forest, the maximum water holding capacity of *Taiwania cryptomenoides- Liriodendron chinensis* mixed forest was significantly increased, and the field water holding capacity of 0 ~ 15 cm soil layer in different stands did not reach significant difference. Except for *Taiwania cryptomenoides*, the maximum water holding capacity and field water holding capacity of other stands increased with the increase of soil depth. Among them, the maximum water holding capacity and field water holding capacity of 15 ~ 30 cm soil layer of *Taiwania cryptomenoides -Liriodendron chinensis* mixed forest and *Liriodendron chinensis* mixed forest were significantly higher than those of *Taiwania cryptomenoides* pure forest and Liriodendron chinensis pure forest ($P \leq 0.05$), but there was no significant difference between 0 ~ 15 cm soil layer.

Soil is the matrix of plant growth, and its physical and chemical characteristics determine the distribution of plant community types. At the same time, the plant community reacts on the soil to improve its habitat conditions and make the community develop. Through the analysis of soil chemical properties under different stands, the results show that there are some differences in soil properties under different stands (**Table 6**). Among the eight stands, the contents of TP, SOM and TN in the soil of *Choerospondias axillaris* forest were the highest, the contents of NH_4-N and NO_3-N in *Quercus acutissima* forest were higher than those in other stands, the AP content of *Taiwania cryptomenoides* was the highest, and the SOM content of shrub grassland was significantly lower than that of plantation. There were significant differences in SOM, TN, NO_3-N, NH_4-N and AP contents in the soil of the eight stands.

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Thickness of soil layer (cm)	Stand type	Moisture content (100%)	Bulk density (g/cm^3)	Maximum water holding capacity (100%)	Minimum water holding capacity (100%)	Total porosity (100%)
0-15 cm	*Liriodendron chinensis*	0.15 ± 0.05b	1.39 ± 0.02ab	0.24 ± 0.02a	0.22 ± 0.03a	0.33 ± 0.03b
	Taiwania cryptomenoides- Liriodendron chinensis	0.32 ± 0.03a	1.29 ± 0.03ab	0.36 ± 0.02a	0.33 ± 0.03a	0.46 ± 0.02a
	Taiwania cryptomenoides	0.18 ± 0.01b	1.47 ± 0.01a	0.24 ± 0.01a	0.22 ± 0.01a	0.36 ± 0.01b
	shrub grassland	0.23 ± 0.03ab	1.21 ± 0.13b	0.35 ± 0.07a	0.28 ± 0.04a	0.41 ± 0.04a
15-30 cm	*Liriodendron chinensis*	0.16 ± 0.01b	1.38 ± 0.04a	0.28 ± 0.01b	0.23 ± 0.01b	0.34 ± 0.01d
	Taiwania cryptomenoides- Liriodendron chinensis	0.33 ± 0.01a	1.22 ± 0.02ab	0.40 ± 0.02a	0.34 ± 0.02a	0.49 ± 0.01a
	Taiwania cryptomenoides	0.17 ± 0.01b	1.39 ± 0.06a	0.24 ± 0.02b	0.20 ± 0.01b	0.38 ± 0.01c
	shrub grassland	0.29 ± 0.05a	1.13 ± 0.11b	0.40 ± 0.06a	0.33 ± 0.05a	0.43 ± 0.02b

Note: Mean ± standard error; the same letter means no significant difference; no same letter means significant difference.

Table 5.
Soil physical properties of different stands.

Tree species	TP g/kg	SOM g/kg	TN g/kg	NH4-N Mg/kg	NO3-N Mg/kg	AP Mg/kg
Choerospondias axillaris	0.40 ± 0.01a	74.13 ± 0.46a	3.31 ± 0.08a	29.87 ± 0.37c	15.46 ± 0.33 g	1.79 ± 0.05d
Corylus chinensis	0.32 ± 0.01b	45.16 ± 0.20e	2.29 ± 0.03d	26.83 ± 0.03e	23.66 ± 0.06d	1.31 ± 0.02f
Cupressus lusitanica	0.35 ± 0.01b	41.58 ± 0.01f	2.09 ± 0.01e	20.87 ± 0.04 h	19.73 ± 0.12e	0.50 ± 0.01 h
Liriodendron chinensis	0.35 ± 0.01b	57.96 ± 0.08c	2.83 ± 0.03c	26.00 ± 0.11f	17.76 ± 0.06f	1.90 ± 0.03c
Taiwania cryptomenoides	0.34 ± 0.00b	65.83 ± 0.19b	3.09 ± 0.01b	20.85 ± 0.01 h	12.44 ± 0.06 h	2.26 ± 0.02a
Nyssa sinensis	0.27 ± 0.02c	48.56 ± 0.04d	2.28 ± 0.01d	31.00 ± 0.06b	25.27 ± 0.07c	2.08 ± 0.03b
Quercus acutissima	0.35 ± 0.02b	41.65 ± 0.20f	2.08 ± 0.02e	35.83 ± 0.14a	33.85 ± 0.03a	0.67 ± 0.04 g
Toona sinensis	0.27 ± 0.02c	33.70 ± 0.10 g	1.90 ± 0.03f	27.69 ± 0.06d	32.41 ± 0.27b	1.49 ± 0.01e
shrub grassland	0.40 ± 0.01a	25.92 ± 0.03 h	1.61 ± 0.04 g	21.68 ± 0.33 g	32.86 ± 0.19b	0.43 ± 0.02 h

Note: Mean ± standard error; the same letter means no significant difference; no same letter means significant difference; TP: soil total phosphorus; SOM: soil organic matter; TN: Soil total nitrogen; NH_4-N: Soil ammonium nitrogen; NO_3-N: Soil nitrate nitrogen; AP: Soil available phosphorus.

Table 6.
Soil nutrient difference analysis of different afforestation tree species.

5. Discussion

5.1 Growth patterns of different plantations

According to the analysis of the growth patterns of the eight tree species in the Xiangxi Rocky Desertification Area from three aspects, (1) the total growth of DBH of 8 tree species increased with age. In contrast, the growth of DBH of 8 tree species in this area is slightly less than that in other areas, which may be due to the single community structure, barren soil, uneven thickness of soil layer, and lack of nitrogen, phosphorus, potassium and other elements to promote plant growth, root growth is hindered, resulting in a smaller DBH growth and lower productivity. (2) With the growth and development of trees, the canopy density gradually increased, the competition among individuals was obvious, the growth space was insufficient, and the growth rate of successive years was significantly slowed down, which led to the differences in the growth of various tree species. (3) The total volume growth of 8 tree species increased with the growth of age, but the time when each stand reached the main cutting age was different. Therefore, it can be seen that in the rapid growth period of 8 kinds of stands, water and fertilizer management and appropriate thinning should be strengthened to control the stand density (see [12]). The rapid growth period should be fully utilized to effectively promote the rapid growth of tree height and DBH, so as to improve the productivity.

5.2 Stand biomass and its distribution pattern

According to the stand productivity of the eight tree species, it can be seen that broad-leaved branches and leaves are more developed than coniferous trees (see [13]). For example, due to its own biological characteristics, flexible material and low shrinkage rate, the stand productivity of *Choerospondias axillaris* is larger than that of *Taiwania cryptomerioides*, although its age is smaller than that of *Taiwania cryptomerioides*. Therefore, in the process of vegetation restoration in karst areas, priority should be given to broadleaved trees such as *Choerospondias axillaris* and *Toona sinensis* or mixed afforestation with coniferous and broad-leaved trees. Studies have shown that the average individual biomass of broad-leaved tree species decreases with increasing altitude, while the biomass of coniferous tree species gradually increases (see [14]). According to the niche in the area, the trees, shrubs and grasses should be arranged reasonably to make full use of the favorable conditions of the microclimate environment in the forest land to promote the biomass accumulation (see [15]). At the same time, proper assessment and management of these forest stands is essential to ensure the health of the forest ecosystem (see [16]).

5.3 Differences of undergrowth plant diversity in different stands

Species richness can be used to measure the quantitative characteristics of species in the community, and the overall diversity index of plant species under different tree species is not high. The Shannon Wiener index of unforested shrub grassland is higher than that of woodland, which is due to the fact that most vegetation biodiversity is caused by herbaceous plants. There is no tall tree layer in the shrub grassland, and its light environment conditions are better than those under the forested forest, which is conducive to the growth and development of shrubs and herbs; the dominant species of shrub layer in the shrub grassland are *Rhus chinensis*, *Rubus tephrodes* and other light loving plants, while the herb layer is mainly perennial herbs such as *Erigeron acris*, etc., which are light loving, semi shade, wet and drought tolerant; plant diversity index and organic matter with the physiological characteristics of bacteria at the soil level of the soil layer (o layer) are related (see [17]). The adaptability of each species to different environments is different, and the differences of light environment on the landing surface of different groups lead to significant differences in dominant species of shrubs and herbs (see [18]). This shows that the environment is heterogeneous and complex, Highly diverse plant combinations can better stimulate plant–soil feedback, and increasing plant diversity is an important strategy to improve the stability of fragile ecosystems. At the same time, related research shows that certain plants (such as *Miscanthus sinensis* Anderssons and *Leguminosae sp.*) should be used first to establish a diversified plant community for rapid vegetation restoration (see [19]).

5.4 The regeneration difference of young trees in different stands

Natural regeneration of multiple tree species occurred under all native tree species, *Taiwania cryptomerioides* and *Toona sinensis* is more prominent, and the natural regeneration of each stand has become stable. There are few species of undergrowth plants in a few rare tree species stands, but they grow well, which is closely related to the growth of trees. Before afforestation, the area was generally wasteland, and there were almost no shrub and herb species. After 40 years of afforestation, the species and quantity of shrubs and herbs increased significantly, and the natural succession of forest ecosystem was an endothermic and spontaneous reaction. Finding key species is essential for understanding the role of species diversity in ecosystem functions (see [20]), and the balance between intraspecific and interspecific competition plays a major role in the functional relationship of biodiversity ecosystems. Although light is a key environmental factor that affects understory communities and diversity, other environmental variables (such as soil nutrients and soil moisture) are also important (see [21, 22]).

5.5 The difference of soil physical and chemical properties among different stands

Soil organic matter, nitrogen and phosphorus are the main nutrient indicators of soil, and organic matter is also an important factor in the formation of soil structure (see [23]). In this study, the SOM, TN, NH4-N and NO_3-N of *Liriodendron chinense* forest were higher than those of *Taiwania cryptomenoides* forest, It is consistent with the conclusion of Geng, that is: the soil organic carbon content of broad-leaved forest was significantly higher than that of coniferous forest (see [24]). Compared with coniferous forest, the concentration of organic carbon and total nitrogen in the aggregates of broad-leaved forest increased, and the stability of aggregates increased, which was beneficial to soil total organic carbon and soil activity Organic carbon accumulation. Studies have shown that the planting density of mixed *larch* plantations significantly affects soil bulk density, soil porosity, total nitrogen, total phosphorus, available nitrogen and available phosphorus (see [25]), and the establishment of artificial *Haloxylon ammodendron* forest can prevent sand damage, It can also change the physical and chemical properties of soil and improve soil fertility (see [26]), which further shows that soil organic matter plays a very important role in improving soil physical and chemical properties and promoting nutrient cycling (see [27, 28]).

6. Conclusions

This study proved that silviculture can quickly realize forest restoration in rocky desertification area. Afforestation technology should focus on afforestation land preparation, tree species selection and forest protection. In order to realize the sustainable forest with multi tree species and multi canopy, the rational application

Figure 7.
Aerial view of afforested land.

of mixed forest in the process of forest management should be paid more attention. This study is only the first step of forest vegetation restoration in rocky desertification area, and the future work will focus on how to cultivate the next generation of sustainable near natural forest (**Figure 7**).

Due to the poor site conditions and poor water distribution in rocky desertification areas, many areas have failed in the process of planting pure forest or mixed forest. For example, the survival rate of young forest is very low because the ecological and physiological relationship between species is not satisfied. The main reason is that the ecological and physiological relationship between species is properly handled. At the same time, the cost is saved and the probability of improper tending is reduced. Not only the pioneer tree species are successful, but also the saplings of multi tree species begin natural succession, which finally forms multi tree species and multi canopy in rocky desertification area, The experimental site provides a good reference template for vegetation restoration in rocky desertification areas.

It is suggested that trees form the families such as *Fagaceae*, *Lauraceae*, *Magnoliaceae*, *Camelliaceae* and *Cerambycidae* should be selected as drought resistant, (see [29]). barren trees with strong regeneration ability, high economic and ecological value and high water and light energy utilization rate in the rocky desertification area, and multi tree species, multi-layer and stable mixture of different ages should be built by mixing forest.

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