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RESEARCH ARTICLE

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Effects of site management treatments on growth of six-year-old, second-rotation Chinese fir (*Cunninghamia lanceolata*) plantations

Abstract The effects of five different site management treatments on the productivity of a six-year-old and second-rotation Chinese fir (*Cunninghamia lanceolata* (Lamb.) Hook.) plantations planted after harvesting a 29-year-old and first-rotation Chinese fir plantation in Xiayang State Forest Farm, Nanping, Fujian Province, were studied. Results showed that the Chinese fir grew best on plots treated with the double slash treatment (BL_3), followed by the whole tree harvest (BL_1) and the slash burning treatment (SB), and poorest on treatment BL_2 (normal slash retention) and BL_0 (removal of all organic matter aboveground). The site index of the second rotation Chinese fir plantations in BL_3 and BL_0 treatments increased by 0.56 and 0.27, respectively, compared with the first rotation, and decreased in the rest of the three treatments. Compared with the first rotation, the site index of the second rotation treated with BL_1, SB and BL_2 treatments decreased by 0.39, 0.45 and 0.63, respectively. Differences among the treatments were not statistically significant.

Keywords Chinese fir, second rotation, site management, growth, site index

1 Introduction

Chinese fir (*Cunninghamia lanceolata* (Lamb.) Hook.) is one of the most important tree species for the supply of timber in south China. However, along with an enlargement of the area of Chinese fir plantations, replanting is increasing on the sites where one or more rotations of Chinese fir have been harvested, which clearly results in soil degradation and productivity decline (Sheng, 1995; Yang, 1997). Although there were many reports on soil fertility and productivity in different rotations of Chinese fir plantations in China (Fang, 1987; Yu and Zhang, 1989; Zhang and Yu, 1992; Yang et al., 1998; Ma et al., 2000; Yu et al., 2000), the observations were made mostly on temporary sites, and firm evidence of productivity change over successive rotations was meager with few reliable data (Evans, 1999). Therefore, with the financial support of CIFOR (Center for International Forestry Research), a long-term research project has been initiated in 1996 to study the effects of various site managements on the productivity of a second rotation Chinese fir plantation established by clearly felling a 29-year-old, first rotation Chinese fir plantation in Xiayang Forest Farm, Nanping, Fujian Province, China. Participants of this project have reported the productivity (Ying et al., 2001a) and soil properties (Weng et al., 2001) of the first-rotation plantation, and the effects of site management on the growth of the second-rotation Chinese fir at 1–5 years of age (Fan et al., 1998, 1999; Yang and Ying, 1999; Fan et al., 2000; Lin et al., 2001; Fan et al., 2002; He et al., 2002, 2003; Fan et al., 2006) and on some soil properties (Ying et al., 2001b).

2 Site description

The experimental site is located in Xiayang Forest Farm, Nanping, Fujian Province, China, at a latitude of 26°48′N and longitude of 117°59′E. The altitude is 200–260 m and the slope degree is 28°–36°. According to the data from the local weather station during 1971–2000, the mean annual precipitation was 1,653 mm, the mean annual temperature was 19.5°C, the average temperatures in January and July was 9.7°C and 28.7°C respectively, and the extreme temperature ranged from −5.8°C to 41°C. The annual

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sunshine is 1,709 h. The red soil was over 100 cm deep and very fertile, making it suitable for the growth of Chinese fir.

3 Experimental design and methods

A randomized complete block design of five plots in each of four blocks was established on a cleared area of the first-rotation Chinese fir plantation. Each plot covers an area of 600 m^2 and was planted with 150 trees. The five residue treatments are:

BL_0: no slash. All aboveground organic residue including the crop trees, understorey and litter was removed from the plots;

BL_1: whole-tree harvest. All the aboveground parts of the trees were removed;

BL_2: stem + bark harvest. Only the main bole and attached bark was removed;

BL_3: double slash. Branches, leaves and other non-commercial components of trees from the BL_1 treatment were applied to this treatment;

SB: stem and bark harvest + burning. The same as BL_2 except that the residue was burned.

Holes, 50 cm × 50 cm × 40 cm, were hand dug at each planting spot. Seedlings were planted in February 1997. Compound fertilizer (contents of N, P and K were unknown) at a rate of 100 g per seedling was applied in May 1997. Because of poor initial survival associated with weed competition, dead trees were replaced in December 1997. The plots were hand cultivated twice a year in 1997, 1998 and 1999, and once in 2000.

Annual measurements of the growth of Chinese fir included height, diameter at breast height (DBH) (or basal diameter), crown width and the survival rate. Plantation age was six years when it was measured in January 2003.

Stem analysis data of the dominant trees of the first-rotation plantation from all the plots were used to fit the polymorphic site index model proposed by Sloboda (Hui and Sheng, 1996) for estimating the site indexes of the first and second-rotation Chinese fir plantations.

Aboveground biomass (including stems, bark, branches and leaves) measurements of the Chinese fir were estimated by the equations developed from the trees sampled every year.

4 Results and analysis

4.1 Sloboda's polymorphic site index model

The polymorphic site index model proposed by Sloboda was fitted using the stem analysis data of the height growth of 20 dominant trees from the first rotation. The model is

$$H = d \times \left(\frac{SI}{d}\right)^{\exp\left(\frac{-b}{c\times 20^c}+\frac{b}{c\times A^c}\right)} \tag{1}$$

H = d*(SI/d)^EXP(−b/(c*20^c) + b/(c*A^c)) (2)

where Eqs. (1) and (2) are the polymorphic site index model proposed by Sloboda with both algebraic and BASIC language expression; H is the dominant height, SI is the site index (height, in meters, of dominant trees at the base age of 20 years); 20 is the base age; exp is the base for the natural logarithm (approximately 2.718,28). The results of fitting: $d = 278.046,3$, $b = 0.361,307,9$, $c = 0.207,516,6$, n (sample number) = 580 and $R^2 = 0.958,4$.

4.2 Growth of Chinese fir plantation six years after planting

Based on the data of the biomass of various components and the stem volume from the trees sampled every year in January from 1998 to 2003, the aboveground biomass and stem volume equations were developed to estimate the biomass and stem volume growth of the Chinese fir plantation. The results were shown in Table 1.

Growth measurements of Chinese fir plantations in different plots six years after planting were shown in Table 2.

Because of poorer soil fertility and other reasons, the difference in the growth of Chinese fir between block III and other blocks was obvious (Table 3). Thus, block III was excluded from the trial in order to reduce the impact of site discrepancy on the results and to estimate the effects of treatments on the growth of Chinese fir accurately (Table 4). The results of tree growth are reported with the replanted trees excluded.

Table 1 Regressions of biomass of various components and outside-bark stem volume of a single Chinese fir plant on its base diameter and height at one to six years old

Age	Components	Regression equation	R	N	DG range	H range
1–6	Leaf	$W_L = 4.307,962 \times (DG^2 \times H)^{0.980,9459} + 95.411,68$	0.970,01	46	0.64–18.1	0.50–8.26
1–6	Branch	$W_B = 1.680,117 \times (DG^2 \times H)^{1.058,604} + 44.077,81$	0.983,79	46	0.64–18.1	0.50–8.26
1–6	Stem	$W_S = 3.545,346 \times (DG^2 \times H)^{1.055,461} + 49.967,99$	0.998,66	46	0.64–18.1	0.50–8.26
1–6	Bark	$W_{BK} = 0.889,739,9 \times (DG^2 \times H)^{1.018,265} + 18.596,77$	0.992,59	46	0.64–18.1	0.50–8.26
3–6	Stem volume	$V = 8.446,69 \times 10^{-6} \times (DG^2 \times H)^{1.120,080} + 0.001,305,649$	0.998,32	22	4.73–18.1	2.01–8.26

Note: DG: ground diameter (cm); H: height (m); W: biomass (g/tree), V: stem volume (m^3/tree); N: sample number.

Table 2 Growth of six-year-old Chinese fir in different plots

Block	Plot	Treatment	Base diameter /cm	DBH /cm	Height /m	Dominant height /m	Density /(stem · hm^{-2})	Volume in trees /(m^3 · tree^{-1})	Biomass in trees /(kg · tree^{-1})	Index of the first rotation	Index of the second rotation	Site index difference between the two rotations
I	1	BL_0	15.33	11.79	7.48	9.16	1,995	0.037,72	22.58	19.95	20.30	0.35
I	4	BL_1	15.15	11.58	7.05	9.29	2,163	0.034,50	20.75	20.58	20.52	−0.06
I	2	BL_2	14.89	11.21	7.09	8.78	1,803	0.033,44	20.14	20.31	19.65	−0.66
I	5	BL_3	16.44	12.39	7.47	9.69	2,019	0.043,84	26.01	21.21	21.19	−0.02
I	3	SB	14.70	10.90	6.61	8.04	1,731	0.030,17	18.27	19.86	18.36	−1.50
II	4	BL_0	13.11	9.86	6.58	8.79	2,260	0.023,53	14.40	18.6	19.66	1.06
II	2	BL_1	14.30	10.62	6.77	8.52	1,923	0.029,18	17.69	18.87	19.20	0.33
II	1	BL_2	14.18	10.40	6.74	8.44	2,332	0.028,52	17.31	19.41	19.06	−0.35
II	5	BL_3	14.15	10.81	7.16	8.87	1,827	0.030,29	18.34	17.89	19.80	1.91
II	3	SB	14.41	10.99	7.08	8.78	2,260	0.031,12	18.81	19.50	19.65	0.15
III	2	BL_0	14.03	10.11	6.00	7.62	1,827	0.024,63	15.05	18.42	17.62	−0.80
III	3	BL_1	11.64	8.30	5.44	6.68	1,827	0.015,06	9.34	18.42	15.93	−2.49
III	5	BL_2	10.43	7.19	4.92	7.14	1,370	0.010,92	6.78	18.60	16.77	−1.83
III	1	BL_3	12.46	8.93	5.83	7.17	2,091	0.018,62	11.49	18.78	16.82	−1.96
III	4	SB	12.56	8.90	5.72	7.74	1,731	0.018,56	11.46	18.78	17.84	−0.94
IV	3	BL_0	14.25	10.86	7.18	8.61	1,952	0.030,84	18.65	19.95	19.35	−0.60
IV	5	BL_1	14.78	11.19	6.95	8.69	1,714	0.032,21	19.44	20.94	19.49	−1.45
IV	1	BL_2	14.33	10.84	7.16	8.86	2,262	0.031,12	18.81	20.67	19.78	−0.89
IV	4	BL_3	15.24	11.86	7.50	9.20	1,905	0.037,36	22.37	20.58	20.36	−0.22
IV	2	SB	14.51	11.14	7.38	8.85	1,667	0.033,02	19.90	19.77	19.77	0

Table 3 Growth of six-year-old Chinese fir in different blocks

Block	Base diameter /cm	DBH /cm	Height /m	Dominant height /m	Density /(stem · hm^{-2})	Volume in trees /(m^3 · tree^{-1})	Biomass in trees /(kg · tree^{-1})	Site index of the first rotation	Site index of the second rotation	Site index difference between the two rotations
I	15.30	11.57	7.14	8.99	1,942	0.035,93	21.55	20.38	20.00	−0.38
II	14.03	10.54	6.87	8.68	2,120	0.028,53	17.31	18.85	19.47	0.62
III	12.22	8.69	5.58	7.27	1,769	0.017,56	10.82	18.60	17.00	−1.60
IV	14.62	11.18	7.23	8.84	1,900	0.032,91	19.84	20.38	19.75	−0.63
LSD $p = 0.05$	1.09	0.90	0.43	0.54	304	0.005,54	3.22	0.67	0.94	0.98

Table 4 Effects of treatments on the growth of six-year-old Chinese fir (blocks I, II and IV)

Treatment	Soil organic C before treatment /%	Base diameter /cm	DBH /cm	Height /m	Dominant height /m	Density /(stem · hm^{-2})	Volume in trees /(m^3 · tree^{-1})	Biomass in trees /(kg · tree^{-1})	Site index of the first rotation	Site index of the second rotation	Site index difference between the two rotations
BL_0	3.17	14.23	10.84	7.08	8.85	2,069	0.030,70	18.54	19.50	19.77	0.27
BL_1	3.38	14.74	11.13	6.92	8.83	1,933	0.031,96	19.29	20.13	19.74	−0.39
BL_2	2.84	14.47	10.82	7.00	8.69	2,132	0.031,03	18.76	20.13	19.50	−0.63
BL_3	3.47	15.28	11.69	7.38	9.25	1,917	0.037,16	22.24	19.89	20.45	0.56
SB	3.32	14.54	11.01	7.02	8.56	1,886	0.031,44	18.99	19.71	19.26	−0.45
LSD $p = 0.05$	0.82	1.38	1.15	0.56	0.66	4,28	0.008,59	4.92	1.89	1.14	1.60

There is no significant difference ($p > 0.05$) in the site index of the first rotation among the sites before treatment (Table 4). Therefore, the results of the trial were comparable.

In the sixth year after treatment, Chinese fir grew best on double slash plots (BL_3); whole tree harvest treatment (BL_1) had the lowest tree height, the third highest dominant height and the second highest values in the rest of the growth measurements; the slash burning treatment (SB) had the third highest values in all the growth measurements except for the dominant height with the lowest value; BL_2 (normal slash retention) had the next lowest values in all the growth measurements except for DBH with the lowest value; BL_0 (removal of all aboveground organic matter) had the second highest height and dominant height, the next lowest DBH and the lowest values in the rest of the growth measurements. However, the analysis of variance showed that there was no statistically significant difference in tree growth among different treatments ($p > 0.05$).

Six years after treatment, the site index of the second-rotation Chinese fir in the double slash treatment (BL_3) and the removal of all aboveground organic matter treatment (BL_0) increased by 0.56 and 0.27 respectively compared with the first rotation, but slightly declined in the rest of the three treatments by 0.39, 0.45 and 0.63, respectively, in the whole tree harvest (BL_1), slash burning (SB) and normal slash retention treatment (BL_2), respectively. However, no significant difference in the change of the site index between the two rotations was found among different treatments ($p > 0.05$).

Trees grew best on the double slash treatment (BL_3) probably due to the mulching effects that inhibited understorey competition and at the same time improved soil moisture retention, and due to the improved soil fertility by nutrient release and soil pH values increase caused by slash decomposition. The apparent slightly better growth of the BL_0 (removal of all aboveground organic matter) in the first four years after planting may also be due to the reduction of competing vegetation which favor the growth of Chinese fir. However, nutrient losses and decreased soil pH values caused by slash removal (Ying et al., 2001b) had negative effects on the long-term productivity. At age six, tree growth measurements in the complete removal treatment (BL_0) were the lowest or the second lowest except for tree height and dominant height. Tree growth in the slash burning treatment (SB) was slightly higher compared with that in the normal slash retention treatment (BL_2) due to high initial availability of nutrients released by the burning of residue which stimulated tree growth in the early stage. However, no significant difference was found among different treatments. Tree growth in the first three years after planting on whole tree harvest plots (BL_1) were the lowest probably because of the increase in competing vegetation which restrained tree growth, but in the fourth year, base diameter and dominant height reached to the fourth highest; in the fifth year, height, tree biomass and volume still remained the lowest while base diameter and DBH reached to the fourth highest, and dominant height reached to the second highest; in the sixth year, tree height still remained the lowest, dominant height declined to the third highest, and the rest of the measurements reached to the second highest.

Although differences of soil fertility among different treatment plots before the trial were not significant, but they had some impacts on the results. Soil organic C is an important index of soil fertility. Before treatment, soil organic C was the highest in the BL_3 treatment (3.47%) while lowest in the BL_2 treatment (2.84%) (Table 4).

The best treatment for tree growth (BL_3) was arranged in the most fertile site, so the trees grew the best too. The most infertile sites were arranged with the next best treatment, so the tree growth did not showed what we had expected.

5 Conclusion and discussion

Six years after treatment, double slash (BL_3) was the best treatment in tree growth measurements, followed by the whole tree harvest (BL_1) and the slash burning treatment (SB), and poorest in normal the slash retention treatment (BL_2) and treatment BL_0 (removal of all aboveground organic matter), but all the difference was not significant.

At age six, the site index of the second rotation Chinese fir plantations in the BL_3 and BL_0 treatments increased by 0.56 and 0.27, respectively, compared with that of the first rotation, and slightly decreased in the rest of the three treatments. Compared with that of the first rotation, the site index of the second rotation treated with BL_1, SB and BL_2 treatments decreased by 0.39, 0.45 and 0.63, respectively. Differences between the treatments were not statistically significant.

The best treatment for tree growth (BL_3) was arranged in the most fertile site, so the trees grew the best too. The most infertile sites were arranged with the next best treatment, so the tree growth did not showed the expected better growth. From the treatment data, the site index declined more greatly in the plots with low soil fertility, or treatment sites of the Chinese fir plantation with low soil fertility had greater tendency towards soil deterioration over successive rotations.

In addition to soil fertility, the growth of Chinese fir in the early stage was influenced by competing vegetation and tending. Therefore, data from future measurements (10 or 15 yeas later) will be used to explore more fully the long-term effects of treatments.

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