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# Effects of site conditions and methods of cultivation on growth of sawtooth oak plantations

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**Abstract** The effects of site conditions and cultivation on the growth of sawtooth oak (*Quercus acutissima* Carr.) plantations were evaluated at the Hongyashan forest farm, in Chuzhou City, Anhui Province, China. The results indicate that the position on the slope, the amount of gravel and the thickness of the soil were important factors in the growth of the sawtooth oak. Lower slope positions with small amounts of gravel and a thick soil were better for the growth of this species than middle slope positions with more gravel and a thin soil. Given the site conditions of the hilly and mountainous areas in Chuzhou City, the mixed Chinese fir (*Cunninghamia lanceolata* Hook.) and sawtooth oak forests did not improve forest productivity compared with pure sawtooth oak forests. Both urea and compound fertilizers promoted the growth of sawtooth oak, as did site preparation and intercropping. Two years after planting, the height growth of ordinary seedlings with a starting height of 0.6 m was higher than that of supper seedlings with a starting height of 1.0 m. Compared with planting, the early growth of the coppices was faster, but the later growth of the coppices was slower.

**Keywords** site condition, cultivation, sawtooth oak, growth

## 1 Introduction

Sawtooth oak is a deciduous tree species of the beech family. It is mainly distributed in warm temperate and

subtropical regions. The Sawtooth oak has characteristics of intolerance to shade and is resistant to drought and barren soils, so it can be planted in mountains and hilly areas for soil and water conservation (Arboretum Editor Committee of China, 1981; Yang et al., 1997; Yang and Jiang, 2001). Sometimes, regeneration by sprouting is used in the management of sawtooth oak plantations in order to reduce the cost of planting and increase the economic benefits (Cai et al., 2001; Lu et al., 2003; Luo, 2006). The wood of sawtooth oak can be used to make good furniture and ships because it is hard and remains quite resistant to wood rot for long periods of time. The stems and branches of sawtooth oak are important media for cultivating mushrooms, such as the shiitake mushroom and auricularia. The bark and fruit shells of sawtooth oak are rich in tannin. The seeds are rich in starch. The tender leaves have abundant protein, amino acid and carotene (Arboretum Editor Committee of China, 1981; Fang and Ding, 1996; Zou et al., 1997; Du et al., 2003; Yu et al., 2005b; Guo et al., 2006). Sawtooth oak is an important source of fuel wood in the hilly and mountain areas of China and it has been suggested that sawtooth oak plantations could play an important role in developing bio-energy forests in the future (Cai et al., 2001; Afforestation Office of State Forestry Administration, 2003; Chen et al., 2004; Zhu, 2006).

Recently, given the adjustments to our national forestry policies, bio-energy forests of sawtooth oak have been developed in the Jianghuai area of Anhui Province, China (Cai et al., 2001). The benefits of sawtooth oak plantations are not so promising, because of unsuitable site selection, extensive management and low processing technology. So, it is necessary and urgent to improve the management of sawtooth oak plantations. In our study, sawtooth oak plantations in Chuzhou City, Anhui Province were investigated to understand the relationships between site conditions, management methods and growth of this species. We are of the opinion that our results will offer important references for increasing the growth rates and benefits of sawtooth oak plantations.

Translated from *Journal of Fujian College of Forestry*, 2008, 28(2): 130–135 [译自: 福建林学院学报]

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## 2 Materials and methods

### 2.1 Study area

Our study area was located at the Hongyashan Forest Farm, Chuzhou City, Anhui Province, China (32°05'N, 118°50'E). The area has a northern subtropical climate with a mean annual precipitation of 1040 mm and a mean annual air temperature of 15.2°C. The soil is thin and developed from pelite and limestone gravel (Cai et al., 2001). As of 2006, the total area of sawtooth oak plantations at the Hongyashan forest farm was about 600 hm<sup>2</sup>.

### 2.2 Methods

In order to understand the effects of site conditions and managements on the growth of sawtooth oak plantations, the following sites were selected in August 2006.

Site A1: In the spring of 1998, sawtooth oak was planted using 1-year-old seedlings which were about 0.6 m in height. The site was on the middle of a slope, a position that had been clear cut of loblolly pine (*Pinus taeda* L.). Soil thickness was less than 20 cm and the amount of gravel was more than 30%. Planting density was 6667 stem/hm<sup>2</sup> and the plantation had been intercropped twice with peanuts (*Arachis hypogaea* L.) after the trees were planted.

Site A2: The site was on a lower slope, where the soil thickness was about 30 cm and the amount of gravel was less than 30%. Other conditions were the same as at site A1.

Site B1: In the spring of 1997, sawtooth oak was planted using 1-year-old seedlings which were also about 0.6 m in height. The site was a clear cut after Chinese fir had been removed. The soil was 20 to 30 cm thick with about 30% gravel content. Peanuts were intercropped twice after tree planting. Some sprout seedlings of Chinese fir were retained and formed a mixed forest of Chinese fir and sawtooth oak with the ratio of 2:8. At the end of April 2004, a compound fertilizer at 600 kg/hm<sup>2</sup> was applied, which consisted of nitrogen (N), phosphorus (P) and potassium (K) (concentrations of K, P and K were 15%, 8% and 7%, respectively).

Site B2: A pure plantation of sawtooth oak was established in the spring of 1997. Other conditions were the same as at site B1.

Site C1: In the spring of 1997, sawtooth oak was planted using 1-year-old seedlings, about 0.6 m high. The site was clear cut of Chinese fir, it had 20 to 30 cm soil thickness and 20% to 30% gravel content. Peanuts were intercropped twice after tree planting. At the end of April 2004, a compound fertilizer at 600 kg/hm<sup>2</sup> was applied.

Site C2: The site conditions were the same as at site C1. At the end of April 2004, urea (concentration of nitrogen was 46%) at 600 kg/hm<sup>2</sup> was applied.

Site D1: In the spring of 2005, sawtooth oak was planted using 1-year-old super seedlings, which were about 1.0 m in height. Peanuts were intercropped twice after tree planting.

Site D2: Ordinary sawtooth oak seedlings, 0.6 m tall, were planted in the spring of 2005. Other conditions were the same as at site D1.

Site E1: The soil thickness was less than 20 cm and the gravel content more than 30%. After an overall soil preparation to a depth of 15 cm, sawtooth oak was planted using 1-year-old seedlings, 0.6 m in height, in the spring of 2002. Peanuts were intercropped twice after tree planting.

Site E2: Site conditions were the same as site E1. After a partial soil preparation to a depth of 15 cm to 20 cm, sawtooth oak was planted, but not intercropped with any crops.

Site F1: In the spring of 1996, sawtooth oak was planted using 1-year-old seedlings, about 0.6 m in height. Peanuts were intercropped twice after tree planting. Soil thickness was about 30 cm and the amount of gravel about 20%.

Site F2: In the spring of 1996, sawtooth oak was planted using 1-year-old seedlings, about 0.6 m tall. At the end of February, 2001, the trees were cut and regenerated by sprouting. The stem and branch biomass of sawtooth oak harvested were 22.0 t/hm<sup>2</sup> and 5.6 t/hm<sup>2</sup> respectively. Site conditions were the same as at site F1.

Three plots of size 10 m × 10 m to 15 m × 15 m at every site were selected. The diameter at breast height and the height of trees in every plot were measured. Three trees, including the dominant tree, the average tree and a subordinate tree at each site were cut down to investigate the weight of stems, branches and leaves. Some fresh samples of these stems, branches and leaves were brought to the laboratory to calculate the dry weight after drying at 70°C. From the data of felled sample trees, biomass regression equations were obtained by applying a relative growth-law (Feng et al., 1999).

$$W_S = 0.04506(D^2H)^{0.9181} \quad R = 0.9953$$

$$W_B = 0.00645(D^2H)^{1.0341} \quad R = 0.9065$$

$$W_L = 0.01142(D^2H)^{0.8434} \quad R = 0.9094$$

where  $D$  is the diameter at breast height (cm),  $H$  the tree height (m),  $W_S$  the stem biomass (kg),  $W_B$  the branch biomass (kg) and  $W_L$  the leaf biomass (kg). From  $F$ -tests, it appeared that the correlation coefficients were statistically significant ( $p < 0.01$ ).

### 2.3 Determination of leaf area and leaf area index

We selected 200 fresh leaves of sawtooth oaks to determinate leaf area by using a LC1200P SCANNER. A mathematical relation between the area and the dry weight of the leaves was established and the leaf area index of the plantations calculated from this mathematical

formula. The results show that the ratio of the area and drying weight of leaves was 11.571 m<sup>2</sup>/kg.

### 3 Results and discussion

#### 3.1 Growth variation under different site conditions

Although the tending measures of site A2 were the same as at site A1, the growth of sawtooth oak plantation at site A2 was larger than that at site A1 (Table 1). Compared to site A1, site A2 was on the lower slope position where soil thickness was larger and the amount of gravel in the soil less. Diameter, height, biomass and leaf area index of the oak at site A2 were larger than those at site A1. It shows that, although this species is resistant to drought and barren soil, the growth was slow under unfavorable site conditions where the soil layer was thin and the amount of gravel high. The slope position, soil thickness and amount of gravel in the soil are important factors in the growth of sawtooth oak. Yu et al. (2005a) mentioned that the slope direction, slope gradient, elevation and soil thickness clearly impacted the growth of sawtooth oak. Its growth was better in the southern slope where the gradient was less than 20° and the soil thickness more than 30 cm.

#### 3.2 Comparison of growth between mixed forest and pure forest

Table 2 shows that the diameter at breast height (DBH) of sawtooth oak in the mixed forest was larger than that in the pure forest and the height of Chinese fir was significantly less than that of the sawtooth oak in the mixed forest. The differences in biomass of stems, branches and leaves were statistically not significant between the mixed forest and the pure forest. It indicates that the growth of Chinese fir is slow under poor conditions in this area even when forest regeneration started from sprouts. We must conclude therefore that mixed forests of Chinese fir and sawtooth oak do not effectively improve forest land productivity compared to pure forests of sawtooth oak under similar site conditions.

#### 3.3 Effect of different fertilizers on the growth of sawtooth oak plantations

After two years of compound fertilizer and urea applications, the above ground biomass of 11-year-old sawtooth oak plantations were 44.1 t/hm<sup>2</sup> and 47.3 t/hm<sup>2</sup>, respectively (Table 3). Although the above ground biomass and the leaf area index of plantations treated with urea was

**Table 1** Biomass of 10-year-old sawtooth oak plantations under different site conditions

site	site condition	stand density/ (stems · hm <sup>-2</sup> )	DBH/cm	height/m	stem biomass /(t · hm <sup>-2</sup> )	branch biomass /(t · hm <sup>-2</sup> )	leaf biomass /(t · hm <sup>-2</sup> )	above ground biomass /(t · hm <sup>-2</sup> )	leaf area index
A1	middle slope, soil depth < 20 cm, gravel content > 30%	5875±240a	4.1±0.2a	5.8±0.2a	21.4±1.2a	5.6±0.3a	3.7±0.2a	30.7±1.6a	4.3±0.2a
A2	lower slope, soil depth > 30 cm, gravel content < 30%	6067±309a	4.7±0.2b	6.7±0.3b	28.1±1.5b	7.4±0.4b	4.8±0.3b	40.3±1.9b	5.6±0.3b

Note: Different letters denote significant differences between both sites at  $p \leq 0.05$  level.

**Table 2** Biomass of 11-year-old mixed Chinese fir and sawtooth oak forests and pure forests of sawtooth oak

site	forest composition	stand density /(stems · hm <sup>-2</sup> )	DBH/cm	height/m	stem biomass /(t · hm <sup>-2</sup> )	branch biomass /(t · hm <sup>-2</sup> )	leaf biomass /(t · hm <sup>-2</sup> )	above ground biomass/(t · hm <sup>-2</sup> )
B1	sawtooth oak	3867±345	6.0±0.3	6.7±0.2	29.6±1.3	8.3±0.3	4.90±0.20	42.8±1.5
	Chinese fir	966±128	6.4±0.2	4.6±0.2	2.4±0.3	0.23±0.03	0.24±0.04	2.9±0.3
	total	4833±436a	6.1±0.4a	6.3±0.3a	32.0±1.5a	8.5±0.4a	5.1±0.3a	45.7±2.3a
B2	sawtooth oak	4666±323a	5.6±0.2a	6.7±0.2a	31.5±1.8a	8.7±0.7a	5.2±0.3a	45.4±2.4a

Note: Different letters denote significant differences between both sites at  $p \leq 0.05$  level. Biomass of Chinese fir was calculated by power law equation (Li et al., 2006)

**Table 3** Effects of compound fertilizer and urea on the biomass of sawtooth oak plantations

site	fertilizer type	stand density /(stems · hm <sup>-2</sup> )	DBH/cm	height/m	stem biomass /(t · hm <sup>-2</sup> )	branch biomass /(t · hm <sup>-2</sup> )	leaf biomass /(t · hm <sup>-2</sup> )	above ground biomass/(t · hm <sup>-2</sup> )	leaf area index
C1	compound fertilizer	4799±232a	5.5±0.2a	6.6±0.3a	30.4±0.8a	8.6±0.5a	5.1±0.3a	44.1±1.9a	6.1±0.3a
C2	urea	4572±394a	5.7±0.3a	6.9±0.4a	32.8±2.7a	9.0±0.4a	5.5±0.4a	47.3±3.2a	6.4±0.4a

Note: Different letters denote significant differences between both sites at  $p \leq 0.05$  level.

larger than those treated with compound fertilizer, there were no significant differences between them. It is necessary to study the long-term effects of different fertilizers on the growth of sawtooth oak and land benefits.

#### 3.4 Growth of sawtooth oak plantations of different sized seedlings

The survival rates of both planted 1.0 m tall super seedlings and ordinary 0.6 m tall seedlings were about 94% (Table 4). The basal area diameter and height of super seedlings, two years after planting, were larger than those of ordinary seedlings. However, the increment and the rate of height growth show an opposite trend. A possible reason is that the roots of super seedlings were more damaged and the water balance more affected when the seedlings were lifted. Although the survival rate of the super seedling plantation was still high, the period of slow root growth might be longer and the early growth slower after planting.

#### 3.5 Effect of soil preparation and intercropping on the growth of sawtooth oak plantations

It is well known that soil preparation can effectively improve physical properties of soil, control weeds, increase soil fertility and promote tree growth. In general, soil preparation can be divided into two types, i.e., overall

soil preparation and partial soil preparation. Intercropping with trees and crops is also an effective measure to improve growth of plantations.

Table 5 indicates that overall soil preparation and intercropping with peanuts cannot only increase the survival rate of sawtooth oak, but also promote the growth of trees under poor site conditions where the soil thickness is less than 20 cm and the amount of gravel in the soil more than 30%. The height of sawtooth oak of the 6-year-old, treated with partial soil preparation was only 0.76 m. However, the height of sawtooth oak in the 6-year-old plantation, treated with complete soil preparation and intercropping with peanuts, was 3.97 m. Therefore, intensive site preparation and intercropping can obviously promote the growth of sawtooth oak if the original site condition was poor.

#### 3.6 Growth of sawtooth oak plantations in different types of regeneration

At site F1 (Table 6), the biomass of stems, branches, leaves and the above ground biomass of the 12-year-old sawtooth oak plantation, were 61.6, 19.9, 9.3 and 90.8 t/hm<sup>2</sup>, respectively. At site F2, the biomass of stems, branches, leaves and above ground biomass, including 6-year-old coppice and planted trees were 57.2, 15.8, 9.6 and 82.6 t/hm<sup>2</sup>, respectively. It shows that the total biomass of

**Table 4** Height growth of sawtooth oak plantations in different size of seedlings

site	seedling height/m	stand density/(stems·hm <sup>-2</sup> )	survive rate/%	basal diameter/cm	height/m	increment of height/m	growing rate of height/%
D1	1.0	6264±306a	94.0±3.3a	2.12±0.02a	1.50±0.04a	0.50±0.04a	50.0±3.5a
D2	0.6	6290±230a	94.3±2.5a	1.69±0.04b	1.21±0.07b	0.61±0.07a	101.7±11.8b

Note: Different letters denote significant differences between both sites at  $p \leq 0.05$  level.

**Table 5** Effects of site preparation and intercropping on the height growth of sawtooth oak plantations

site	management method	stand density/(stems·hm <sup>-2</sup> )	height/m
E1	overall soil preparation, and intercropping with peanuts for two seasons	6040±352a	3.97±0.35a
E2	partial soil preparation, non intercropping	4532±377b	0.76±0.18b

Note: Different letters denote significant differences between both sites at  $p \leq 0.05$  level.

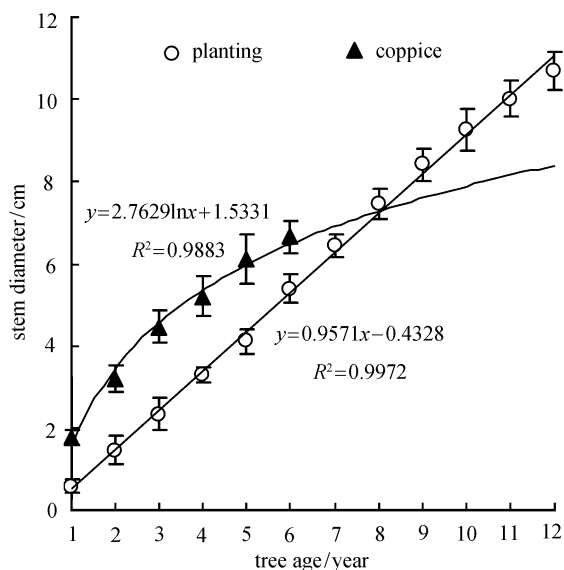
**Table 6** Biomass of sawtooth oak plantations in different regeneration types

site	stand age and regeneration type	biomass composition	stand density/(stems·hm <sup>-2</sup> )	DBH/cm	height/m	stem biomass/(t·hm <sup>-2</sup> )	branch biomass/(t·hm <sup>-2</sup> )	leaf biomass/(t·hm <sup>-2</sup> )	above ground biomass/(t·hm <sup>-2</sup> )
F1	12-year-old, planting in 1996	standing tree	2567±231a	9.1±0.5a	10.3±0.4a	61.6±3.5a	19.9±1.4a	9.3±0.5a	90.8±5.3a
F2	6-year-old, coppice in 2001	standing tree	4550±390b	5.6±0.3b	7.0±0.3b	35.2±2.6	10.2±0.8	5.7±0.3	51.1±2.9
	6-year-old, planting in 1996	cutting tree				22.0	5.6	3.9 <sup>(1)</sup>	31.5
		total				57.2±2.6a	15.8±0.8b	9.6±0.3a	82.6±2.9a

Note: Different letters denote significant differences between both sites at  $p \leq 0.05$  level. The data was calculated using 12.4% of the proportion of leaf biomass to aboveground biomass of sawtooth oak in similar age.

plantations at site F1 was greater than that of the two generations at site F2. Table 6 also shows that the above ground biomass of 6-year-old coppice was 51.1 t/hm<sup>2</sup>, but the above ground biomass of the 6-year-old sawtooth oak, regenerated by planting, was only 31.5 t/hm<sup>2</sup>. This result is similar to the findings of Lu et al. (2003) which shows that the growth rates of sawtooth oak were different with various types of regeneration. Compared with the regeneration of planted sawtooth oak, the early growth of coppice was faster, but the later growth of coppice was slower.

In order to understand the growth process of sawtooth oak, given different types of regeneration, the dynamics of tree rings were investigated (Fig. 1) in the plantations at sites F1 and F2. The relationship between the stem diameter at 20 cm height from the ground up and tree age was fitted with a linear equation for site F1, which was established by planting. The relationship between stem diameter at 20 cm height from the ground and tree age was fitted with a logarithmic equation for site F2, which was regenerated by sprouting. Figure 1 also shows that, before age 8, diameter growth in regeneration by sprouting was faster than that in regeneration by planting. After eight years, this trend was reversed. This result can be explained by the fact that the above ground biomass of the two generations at site F2 was less than that of one generation at site F1 (Table 6). Compared to regeneration by sprouting, the planting for long rotations might be beneficial to biomass accumulation and volume growth. However, if the aim is to cultivate small size timbers such as firewood and medium for cultivating mushrooms, regeneration by sprouting might be a good way, because its rotation period is short and the market risk low.



**Fig. 1** Dynamics of stem diameter at 20 cm height of sawtooth oak for two different types of regeneration

Chen et al. (2004) found that using regeneration by sprouting to cultivate fuel wood from sawtooth oak, was suitable. In site classes II, III and IV, the rotations of the plantations were determined as eight years, ten years and ten years, respectively. The study by Chai et al. (2001) also showed that the economic benefits of regeneration by sprouting were larger than regeneration by planting.

## 4 Conclusions

Although sawtooth oak is resistant to drought and barren soils, its growth shows different responses under various site conditions. The amount of gravel, soil thickness and the slope position are the important growth factors. In general, growth of sawtooth oak is better lower down the slope, where soils are thick and contain only small amounts of gravel.

In the hilly and mountainous areas of Chuzhou City, mixed Chinese fir and sawtooth oak forests do not improve forest productivity compared with pure sawtooth oak forests, because the Chinese fir is not suitable for its site conditions, where the soil layer is thin and the amount of gravel in the soil high. From the two-year fertilizer experiment, we conclude that the effect of the compound fertilizer on the growth of sawtooth oak was similar to the effect of urea.

The basal area diameter and height of planted super seedlings were larger than those of ordinary seedlings two years after planting. However, the increment and the rate of height growth of the super seedlings were not quite as good as those of the ordinary seedlings. The reasons could be that the roots of super seedlings suffered more injuries and the water balance was more unfavorably affected when the seedlings were lifted.

High standards of site preparation and intercropping with peanuts significantly promoted the growth of sawtooth oak under poor site conditions. Compared to planting of sawtooth oak, early growth of regeneration by sprouting was faster, but later growth of regeneration by sprouting was slower. We suggest that the planting of sawtooth oak is the best way to produce large size timbers over long rotations. Conversely, regeneration by sprouting is the better option for producing small size timbers in short rotations.

**Acknowledgements** This work was supported by the "948" project of the Chinese Government (No. 2005-4-44) and a public welfare project of China (No. 200704034).

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