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RESEARCH ARTICLE

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Selection, propagation and cultivation of *Pinus massoniana* clones for pulp use

Abstract Based on the growth, wood property of the ortets, and rooting abilities of cuttings, 32 *Pinus massoniana* clones for pulp use were selected from forests of superior provenance, mixed families, and progeny test of seed orchard by two-step selection. The average height and DBH growth of three-year-old clones were 28.6% and 16.7%, respectively, higher than those from seedlings, and average gain of wood density reached 8.7%. Rooting rate of all these clones was over 80%, 28% higher than the clones selected by a single step. A cutting orchard of 0.33 hm^2 on the hillside was constructed to intensively produce cuttings according to the tests on construction methods, pruning, and fertilization. A total of 50,000 grade Ⅰ, 37,500 grade Ⅱ, and 62,500 grade Ⅲ cuttings were collected per hectare of this cutting orchard each time, and were cut three times each year. With all the above techniques, 48 hm^2 of clonal forests for pulp use of those clones had been planted in five places in Fujian Province. Container stecklings are more likely to increase the planting survival rate.

Keywords *Pinus massoniana*, clones for pulp use, selection, cutting orchard, plantation

1 Introduction

Pinus massoniana is an economically important coniferous species that is widely planted in 17 provinces (districts) in south China, and has been listed in the national scientific and technological projects since “the Sixth Five-Year Plan”. From the beginning of “the Eighth Five-Year Plan”, the *P. massoniana* has been confirmed as an important species for paper pulp use in south China, and has already been studied on many respects such as the collection, preservation, and utilization of gene resources, establishment of production population and breeding population, development of the pulp-use orchard and high-yield techniques of seeds, genetic variation of wood qualities and pulp properties, and selection on superior provenance. Great achievement has been noted in the above study subjects, bringing substantial ecological, economic, and social benefits.

In order to utilize fully the additive and the nonadditive effects of forest genome and to obtain genetic gain to the maximum extent, clone selection is the only way for the improvement of the forest trees. So in recent decades clonal forestry has firstly been used extensively in easily rooting species and then gradually used in species hard to root. *P. massoniana* is a species difficult to root and the cyclophysis effect of ortets is obvious. Its cuttings are of callus-rooting type. Low contents of endogenous IAA, high levels of ABA, iPA, $GA_{1/3}$, and MIn, and high IAA oxidative enzyme activity were the main factors restricting its rooting (Ji et al., 1997, 1998, 1999, 2001). Using proper root promotion techniques, the survival rate of cuttings less than 5 years old meet the requirement of production (Ji et al., 2001). Researches on the variability of rooting ability of cuttings showed a great potential for production when we chose the easily rooting ortets, whether among populations or among individuals within the same population (Ji et al., 1998). Based on the current research and according to the selection goal of pulp-use wood, this study aims to select fast-growing and easy-rooting materials with fine genetic properties, and then uses them to form clones that are useful for the study of cutting orchards and for the preliminary experiment in plantation. All of these would lay a foundation for the propagation and cultivation of *P. massoniana* clones for pulp use.

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2 Materials and methods

2.1 Selection of superior clones for pulp use

2.1.1 Plant materials

The original materials were selected from forests of superior provenances in Wuyi Forest Farm in Zhangping County, Fujian Province: 7-year-old provenance trial forest of Guangxi; 3–4-year-old mixed families from *P. massoniana* seed orchard for pulp use; and 2-year-old progeny test forest from clonal seed orchard.

2.1.2 Primary selection of superior ortets

Superior plants were selected visually from fine stands of provenance and mixed families from seed orchard, and then ortets were chosen according to the selection standards, such as height (20% higher than the average height), crown form, stem straightness, forest diseases, and pests, etc. The selection intensity is 1/1,000–1/2,000. In order to guarantee enough number of cuttings, a superior district was first selected in the progeny test of seed orchard, and then fine plants as ortets were selected in every district.

2.1.3 Selection of fine clones

On the basis of primary selection, cuttings were planted in the fully exposed spraying bed to promote rooting, and treatments of cuttings followed the methods given by Ji et al. (2001). Rooting characteristics of the cuttings, such as rooting rate, total number of roots and root effective index (root effective index = (root average length × total number of roots) / total number of cuttings), were investigated. Such characteristics of ortets with the same age were then compared and combined with wood property (wood density) and the progeny growth of every clone to determine superior ortets. Finally fine clones were selected.

2.2 Construction and management of the cutting orchards

2.2.1 The quantity and quality of the cuttings with different construction methods

Cutting orchards were constructed using the same cuttings both on the hillside and in the field. For the hillside, the terracing land was adopted with the width of 0.8 m, planting space of 10 m, and plant density of around 12,500 stems/hm^2. In the field orchards, the planting space was 0.4 m × 0.8 m and the plant density about 31,200 stems/hm^2.

In mid-June of the planting year, the cutting tops were pruned at 7 cm above ground and the lateral buds were removed but the lateral branches retained. Then the orchards were fertilized once every week using urea + compound fertilizer + water (ratio 2:1:97). The number of cuttings was counted and analyzed in early October of the same year according to the following grading standards: degree Ⅰ, the basal diameter ⩾0.3 cm and the length ⩾7 cm; degree Ⅱ, the basal diameter 0.1–0.3 cm and the length 5–7 cm; and degree Ⅲ, the basement diameter ⩽0.1 cm and the length ⩽5 cm. A total of 60 ortets were investigated three times for different construction methods.

2.2.2 Effects of management methods on quantity and quality of cuttings

The effects of fertilization on the quantity and quality of cuttings in the field were investigated, with watering alone every week as the control. The investigation method was the same as in section 2.2.1.

In mid-June, top and lateral buds of four clones (40 ortets each clone) on the hillside orchard were pruned, with non-pruning as the control with four replications. The number of cuttings and lateral branches germinated in all grades was counted in October.

2.3 Clonal plantation

Since 1998, the stecklings from cuttings had been planted with a density of 1800 stems/hm^2 in site class Ⅱ at five sites in Fujian Province, namely Wuyi, Shaowu, Shunchang, Mingxi, and Yonglin, and compared with container seedlings. Each clone was planted in blocks with 20 ramets in each block and three replications. Finally the survival rate of all plantations and the growth of 3-year-old forest at Wuyi were surveyed.

3 Results and analysis

3.1 Selection of superior clones for pulp use

3.1.1 Primary selection of superior ortets

About 871 superior ortets were selected according to the growth status. Based on the improvement of the original forest, the selection of the ortets was as follows: 150 from fine provenance, 322 from mixed families, and 389 from progeny test of seed orchard. Of the ortets, 150 were 7 years old, 82 were 4 years old, 250 were 3 years old, and 389 were 2 years old according to stand age. The average growth of the ortets were all 20% higher than the original forest, and diameter at breast height (DBH) of the 7-year-old provenance ortets was 50% higher but the rooting rates were all less than 37.4% (Table 1).

3.1.2 The selection of fine clones

Thirty-two clones were selected according to the growth, wood property of ortets, rooting rate of cuttings, and survival

Table 1 Growth comparison of selected ortets and their original forest

Original forest type	Age /year	Growth of forest		Number of ortets and their average growth			Average growth of ortets over the original forest	
		Height /m	DBH /cm	Number	Height /m	DBH /cm	Height /%	DBH /%
Provenance forest	7	4.2	4.4	150	5.2	6.6	23.8	50
Forest of mixed families	4	1.9	–	82	2.3	–	27.8	–
Forest of mixed families	3	1.0	–	250	1.2	–	20.0	–
Forest of progeny test	2	0.37	–	389	0.45	–	21.6	–

rate (over 80%) after three years of test. The character variations among the clones, except for root effective index and ground diameter, were not significant but notably higher than the control (the seedlings) (Table 2). Further analysis showed that the average growth of height and DBH and the rooting rate of the 32 clones were respectively 16.11%, 10.35%, and 28% higher than the others. Of these clones, the average height and DBH growth of three-year-old ones were respectively 28.6% and 16.7% higher than those of seedlings, and all the ortets were selected from superior clones with high wood density of about 0.479,5–0.610,9 g/cm^3 and average gain of wood density was up to 8.7%. The single-tree heritability of wood density of *P. massoniana* reached 62% and the family heritability 57% (Zhou et al., 1994; Fan et al., 2004). Since the wood density is closely related to the pulp wood properties such as the paper pulp gain, fiber composition, and the thickness of tracheid wall, etc., the 32 clones with wood density between 0.562,8–0.610,9 were superior clones for pulp use. The relative test should be carried out after the clones grow up to get direct evidence.

Table 2 Rooting characteristics and growth of 3-year-old forest of the 32 clones

Clone No.	Rooting rate/%	Root effective index	Total root number	Height /cm	GLD/cm	Survival rate /%	Growth of 3-year-old forest		
							Crown width /m	DBH /cm	Height /m
738	92	0.30	20	10	0.55	80	1.6	3.4	2.9
659	92	0.23	30	10	0.60	95	1.6	3.1	2.8
568	87	0.30	26	8.5	0.36	85	1.6	2.3	2.3
588	96	0.36	30	10	0.60	90	1.5	2.7	2.8
490	87	0.23	32	8	0.40	95	1.6	2.5	2.5
236	89	0.34	22	10	0.50	80	1.5	2.3	2.6
323	94	0.33	20	8	0.40	88	2.0	3.2	2.8
686	93	0.35	30	10	0.60	81	1.7	2.8	2.8
742	92	0.31	20	12	0.42	94	1.6	3.5	3.1
223	82	0.39	23	9	0.37	81	1.8	2.8	2.7
260	100	0.29	20	8	0.60	81	1.5	2.7	2.7
519	94	0.21	15	9	0.50	100	1.7	3.4	3.2
665	94	0.32	25	10	0.60	94	1.7	2.8	2.8
661	91	0.31	28	8	0.60	92	1.5	2.8	2.7
8008	91	0.21	25	10	0.50	92	1.6	3.0	2.8
658	89	0.34	25	10	0.60	83	1.7	3.3	3.2
244	93	0.14	21	9	0.37	92	1.9	3.3	3.0
574	89	0.34	28	9	0.50	80	1.8	3.3	3.3
546	85	0.17	18	9	0.45	80	1.8	3.4	3.1
005	91	0.18	30	9	0.36	81	1.8	3.1	3.0
260	82	0.16	30	8.5	0.40	82	1.2	1.9	2.2
720	93	0.20	24	13	0.55	80	1.2	2.1	2.2
411	97	0.34	25	11	0.50	80	1.4	2.4	2.1
520	92	0.32	22	11	0.40	80	1.3	2.2	2.4
590	83	0.22	28	10	0.45	80	1.2	2.4	2.5
589	95	0.23	22	9.5	0.45	80	1.3	2.7	2.4
334	84	0.21	25	10	0.60	92	1.2	2.1	2.3
333	81	0.40	30	10	0.40	80	1.3	2.4	2.2
675	89	0.31	25	11	0.60	80	1.4	2.3	2.2
277	92	0.19	22	10	0.50	92	1.3	2.5	2.5
259	83	0.17	22	12	0.60	80	1.4	2.8	2.5
316	97	0.20	27	11.5	0.50	92	1.3	2.5	2.3
Average	90	0.27	25	9.8	0.50	85.7	1.5	2.8	2.7
CK	–	–	–	12	0.28	95	0.9	2.4	2.1

Table 3 Comparison of quantity and quality of the cuttings from orchard on hillside and in field

Construction method	Average number of cuttings of each ortet				The number of cuttings per hectare			
	Degree Ⅰ	Degree Ⅱ	Degree Ⅲ	Total	Degree Ⅰ	Degree Ⅱ	Degree Ⅲ	Total
Hillside	4	3	5	12	50,000	37,500	62,500	150,000
Field	6	5	8	19	187,200	156,000	249,600	592,800

3.2 The construction and management of the cutting orchards

3.2.1 The quantity and quality of the cuttings in different construction methods

The comparison of quantity and quality of the cuttings from the cutting orchards both on the hillside and in the field (Table 3) showed that the difference between the two construction methods by the single-tree variance analysis was not significant. It was observed that in the field–cutting orchard there were more plump lateral buds that were advantageous to cut next year and will produce more cuttings. Although it was favorable for intensive management, yet the price of field was more expensive and it was difficult to find a suitable place near the breeding field. In 2000, according to the soil condition, water resource, and convenient transportation, a cutting orchard of 0.33 hm^2 on the hillside was constructed to massively produce cuttings. Incidentally, they grew well and could be harvested thrice every year.

3.2.2 Effect of management on quantity and quality of cuttings

The effect of fertilization on the improvement of quantity and quality of cuttings was remarkable compared to the control (none fertilizer except water) (Table 4). The synergic effects of fertilizers for cutting next time could also be illustrated by the number of the germinated lateral buds.

Table 4 Effect of fertilization on improving quantity and quality of cuttings from three-year-old ortets

Treatment	The number of lateral buds per hectare	The number of cuttings per hectare			
		Degree Ⅰ	Degree Ⅱ	Degree Ⅲ	Total
Fertilization	249,600	187,200	156,000	249,600	592,800
CK	124,800	93,600	124,800	187,200	405,600

Pruning combined with fertilization could increase the number of lateral buds, enlarge the crown, and make latent buds germinate to increase the cuttings. The effect of pruning on the quantity and quality of cuttings is shown in Table 5. They have been proved in the other coniferous species such as *Picea asperata*, *Pinus radiate, P. taeda, P. elliottii* × *P. caribaea*, etc. (Wang, 2001).

Table 5 Effect of pruning on the quality and quantity of cuttings from three-year-old ortets

Treatment	The number of lateral branches per ortet	The number of cuttings per ortet			
		Degree Ⅰ	Degree Ⅱ	Degree Ⅲ	Total
Pruning	37	148	89	233	468
CK	16	0	8	98	106

It can be seen that fertilization and pruning could markedly improve the quantity and quality of the cuttings. From the cutting orchards of coniferous species that have been popularized all over the world, insensitive management could curb the aging of ortets, increase harvest times, and improve the rooting rate, etc. (Wang, 2001). These should be perfected and popularized in *P. massoniana* orchards, and further studies should be carried out on the particular management techniques.

3.3 The plantation of clones for pulp use

With these techniques, clonal stands of 48 hm^2 for pulp use with clones mentioned above were planted in site class Ⅱ – Ⅲ with a total of 90,000 stems and a density of 1,800 stems/hm^2 (Table 6). Due to the restriction of the cuttings, the number of clones at some places in 2000 and 2001 did not reach 32. It could be found from Table 6 that using bare-rooted stecklings reduced the survival rate compared to the container stecklings. The substrate should therefore be improved. In this study the substrate was mixed with pinewood topsoil + carbonized sawdust + river sands (1:1:1) and showed certain effects.

Table 6 Plantation of *P. massoniana* clones for pulp use

Year	Location	Planting area /hm^2	Steckling type	Number of clones	Survival rate /%
1998	Wuyi, Zhangping	4.00	Bare-rooted	32	85.7
1999	Wuyi, Zhangping	2.67	Bare-rooted	32	81
	Weimin, Shaowu	2.67	Bare-rooted	32	62
2000	Qiuling, Mingxi	16.67	Bare-rooted	14	57.5
2001	Yangkou, Shunchang	10.00	Container	32	83
	Wuyi, Zhangping	3.33	Container	11	87
	YanJiang, Yongling	6.67	Container	32	82

Considering the growth potential and the juvenility of the young forest after planting, only the three-year-old forest in Zhangping was investigated and the result is presented in Table 2. The average height and DBH of three-year-old ones in these clones were 28.6% and 16.7%, respectively, higher than those from seedlings. Variance analysis shows that there was no significant difference in growth among the clones but marked difference with the control. At the same time it was found that the regulators, which were added to promote rooting, restrained the aboveground growth, but such inhibition disappeared completely in the second year.

4 Conclusions and discussion

Thirty-two *P. massoniana* clones for pulp use were selected from 871 ortets in the first step of selection, based on the growth, cutting rooting ability, survival rate, and wood properties of the ortets. These ortets were selected from the clonal seed orchard for pulp use with a high wood density around 0.479,5–0.610,9 g/cm^3, and the average gain of wood density reached 8.7%. However, further measurements on wood properties and the directly relative properties on pulp should be made so as to select clones conveniently in the future.

Considering the expensive price of fields and the difficulty to find a suitable place near the breeding field, the methods described here were effective in constructing cutting orchards on the hillside with superior soil conditions, water resources, and convenient traffic. Fertilization and pruning could improve the quantity and quality of the cuttings. But in the construction of *P. massoniana* cutting orchards, studies were needed on such aspects as planting density, fertilization time and frequency, pruning intensity, selection and utilization of the plant regulators, and the life span of the ortets.

Clonal forests of about 48 hm^2 for pulp use were planted at the same site class with a total of 90,000 stems in five places in Fujian Province and all the clones grew well. Continual researches should be carried out on each forest in order to study the interaction between the genotype and the environment, estimate the stability of the genotype, and to popularize the clones. Furthermore, the forestation density, management method, and the logging age, etc. need to be studied.

Since *P. massoniana* is a species quite hard to root and the impact of the ortets' age is obvious (Ji et al., 1999), the key subjects for selection of clones will be to strengthen the correlative analysis of early and late-stage characteristics as well as to explore the selection techniques of molecular markers.

P. massoniana clonal afforestation is still immature. In order to meet the demands of construction of commercial forests in south China, the study of selection and breeding of *P. massoniana* clones for pulp use should refer to the experiences of many other conifers such as *Cunninghamia lanceolata*, *Cryptomeria japonica*, *Picea abies*, and *P. radiata*. Furthermore, superior materials such as provenance and families selected since "the Sixth Five-Year Plan" should be preferentially used in future studies. Cross breeding should also be carried out by hybridizing different kinds of genotypes to broaden the genetic resources in clonal forestry of *P. massoniana* and to ensure the clonal forestry is on the right track. The optimization of the propagation of cuttings should also be carried out. In addition, the embryo culture of the *P. massoniana* should be studied in the future to meet the demand of fast propagation and breeding industry.

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