CLONAL SELECTION, PROPAGATION, AND MAINTENANCE OF JUVENILITY OF CHINESE FIR, AND AFFORESTATION WITH MONOCLONAL BLOCKS

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ABSTRACT

Techniques of clonal selection, establishment of hedged stool-beds, and cutting propagation have been developed for *Cunninghamia lanceolata* (Lamb.) Hook. (Chinese fir) in Zhejiang Province, China, and clonal forestry has been implemented in a local programme based at Kaihua County Forest Farm. Cutting propagation and the maintenance of juvenility, and plantation performance of 102 clones in single-row plots and multi-tree blocks, have been studied over different years and sites.

Hedged stool-beds with a density of 6.3 stools/m^2 can provide 40–50 shoots per stool in the third year, when techniques for stimulating shoots have been used. Cuttings taken in the spring have an average rooting success of 90%, height at age 1 year of 35 cm, and basal diameter of 6 mm at a density of 52.5 plants/m^2, at which point they are ready for transplanting to field sites.

Needle cuttings were developed to increase multiplication rates of superior clones. This involves cutting off needles (with a little xylem) from coppice shoots near the root collar, and setting during the period from January to March. Rooting was 85%, the height at age 8 years was 10 m, and diameter at breast height (dbh) was 12.4 cm, a similar performance to that of shoot cuttings. Stands developed from seedlings of elite families and cuttings of the third propagation cycle had a similar growth rate. The performance of successive propagations of cuttings showed no significant decline in rooting and growth over 11 propagation cycles. Hedged stool-beds can prevent trees from ageing and keep shoots at a juvenile stage.

If the test materials are classified into four levels of improvement—"elite clones", "average of best 23 clones", "elite families", and "first-generation seed orchard offspring"—gains in single-tree-volume (STV) at age 9 years were respectively 67%, 24%, and 15% over the seed orchard offspring. Of all selection materials, the best were crosses between selected parents from different provenances. The first screening of clones was carried out at 4–5 years after planting, the second at 6–7 years, and the final screening at 8–12 years (9.5–11.5 m height). Selection of 15 clones out of 102 resulted in a gain of 86% in STV over the Napo, Guangxi, check. Planting single-clone blocks of a genetically-diverse range of clones can increase yields per unit area. Up to the present, 2700 ha have been planted on Kaihua Forest Farm and increases in yield of over 50% are expected.

Keywords: clone; hedged stool-bed; juvenility; cuttings; gain; yield; screening; afforestation; monoclonal blocks; *Cunninghamia lanceolata*.

INTRODUCTION

Chinese fir is a timber species, unique to China, which has high yields, good wood quality, and fast growth. Its timber has a wide range of uses and its geographical distribution stretches across the subtropical area of China (Wu 1984). The annual timber production of Chinese fir accounts for one-quarter to one-fifth of the country's total and the annual planting of Chinese fir reaches over 700 000 ha. Statistics up to 1993 record an area of 9.1 million ha of Chinese fir in China, although not all this is planted.

Tree improvement programmes for Chinese fir were started in the 1960s in China and the first-generation seed orchards of Chinese fir were established with clones of selected superior phenotypes; second-generation clonal seed orchards were established in the 1980s. Provenance tests over the whole distribution area were conducted in the late 1970s (Hong & Chen 1995a, b). Professor Ma Changan, from the Chinese Academy of Forestry, proposed clonal selection of Chinese fir in the 1970s but at that time the necessary technologies had not been developed to implement clonal forestry.

Before the 1950s, reforestation with cuttings of Chinese fir was regarded as a routine practice, going back over 800 years (Pen 1985). After 1950, under the influence of the Russian geneticist D.T.Lysenko, cutting propagation was largely abandoned in favour of seedlings. However, during the last 20 years there has been a resurgence of the use of cuttings, and propagation and rejuvenation techniques have been improved (Li 1995; Li *et al.* 1990).

Clonal forestry, the planting of forests with selected tested clones, requires the following elements for successful development:

- A vegetative propagation system that produces commercial quantities of planting stock, economically.
- Maintenance of juvenility of clones during clonal testing and subsequent commercial propagation, and/or some means of rejuvenation of vegetative material collected from mature trees, to ensure good growth.
- Selection of ortets, testing of large numbers of clones, and selection of the best clones for commercial use.
- Integration of clonal testing with a breeding programme based on recurrent selection.
- Demonstration of the benefits of clonal forestry compared with other methods of deployment of improved stock.
- A forest management system that exploits both potential selection gains and within-clone uniformity.

These essential requirements have been addressed and progressively resolved in a unique local programme, implemented by the senior author at the Kaihua County Forest Farm in Zhejiang province during the last 25 years (Zhou 1990, 1992). The results of this research and development work are reported here.

The Chinese fir tree improvement programme was started at Kaihua in 1973 and a clonal selection programme was initiated in 1978. In 1982, hedged stool-beds were developed by utilising the ability of mature Chinese fir to produce (juvenile) coppice sprouts which were subsequently rooted as cuttings. This proved to be a breakthrough in cutting propagation and in 1985 a first plantation for testing and demonstration of clonal forestry was planted with clones selected from control-pollinated offspring of selected parents. This has attracted wide attention in China, and during the last 8 years about 10 000 people have visited Kaihua Forest Farm to observe and study these techniques.

PROPAGATION BY CUTTINGS FROM STOOL-BEDS

Establishment of Hedged Stool-beds

Hedged stool-beds now provide the major source of cuttings for commercial planting stock at Kaihua. It is clear that the potential superiority of clonal forestry depends on the superior genetic quality of clones in the stool-beds, so initial selection of ortets is critical. Coppice shoots are taken from the root-collar region of selected trees, set, and rooted, and then transplanted into stool-beds at a spacing of 0.2×0.35 m (density of 6.3 stools/m^2) after 1 year's growth in the nursery.

Stock plants in the stool-beds should be pruned every year to maintain their juvenility (i.e., to prevent or at least slow their ageing). To achieve this, the stools are pruned from July to early August in the first year after transplanting, to control height to 0.4–0.5 m; all branches on stools are removed except three to four low branches left to provide nutrients for growth. Weeding, ploughing, and application of nutrients are necessary to stimulate more shoots from the root-collar region.

Stools are progressively removed, as clonal test results on growth and disease resistance become available and as selection of clones becomes finalised (by age 12). Stool-beds are kept in good health and vigour by the cutting back and pruning techniques described above. New stool-beds become necessary for expanded production when the best clones are finally selected.

Shoot cuttings are removed at the root collar the next spring, while keeping newly-developed, healthy shoots on the stool plant. Old stools are cut back the following July to early August and pruned at a height of 0.4–0.5 m, leaving a single new shoot per tree. Collection of cuttings in the spring, keeping one to three shoots, and hedging back in July/August are repeated annually. In this way, old stems and shoots are replaced by newly-developed coppice to prevent or slow ageing of the stools. In addition, clones that show bad performance should always be eliminated from stool-beds to increase the general level of genetic improvement.

Multiplication Rate

As Chinese fir has a strong sprouting ability, plants in the stool-beds will produce coppice shoots about 90 days after they are pruned. One-year-old plants, after being transplanted into stool-beds, can produce 14–20 shoots with lengths of 4–12 cm and basal diameter of 0.2–0.3 cm, with 87–130 cuttings per square metre of bed. By the third year, stool-beds can produce 240–300 shoots/m^2, with 40–50 shoots per stool. One hectare of stool-beds of 3-year-old stock plants can provide from 2.5 to 3.2 million shoots (Table 1).

TABLE 1–Multiplication rates from 1 ha of stool-beds

Year	Number of cuttings per stock plant	Number of cuttings /m^2 stool-beds	Theoretical number of cuttings/ha stool-beds
First year	14–20	87–130	882 000–1 260 000
Second year	25–38	150–230	1 570 000–2 390 000
Third year	40–50	240–300	2 520 000–3 150 000

Cutting Collection and Setting

Cutting nurseries should have deep, fertile soil with good water penetration. Fertiliser should be applied, the beds should be level and covered with 5–8 cm of yellow soil. The cut length of shoots for setting should be 4–12 cm. Cutting collection and setting are done in the spring, from February to March, in overcast or rainy conditions. It is better to set cuttings early rather than late. Spacing is 7 × 15 cm, with a density of 62 cuttings/m^2. Cuttings should be watered thoroughly after setting, and during dry periods frequent watering is needed and/or an overhead shade of plant branches.

Other management measures are the same as those for seedlings. The survival rate of spring-set cuttings is over 90%. No overhead shade is needed in summer except during extreme drought. Per-hectare production cost of cuttings is 10% less than that of seedlings. The height of cuttings 1 year after setting is 35 cm, 8 cm higher than that of seedlings. The diameter at the root collar is 0.6 cm, 0.2 cm larger than that of seedlings; 525 000 cuttings suitable for field planting can be cultivated in 1 ha, or 52.5 plants/m^2.

PROPAGATION BY NEEDLE CUTTINGS

Usually, stool-bed cuttings are used in commercial production of genetically-improved stock of Chinese fir (Fig. 1). However, shoots are often of limited availability for a newly-selected, superior clone, and needle cuttings can be used to boost clone multiplication rates. For this purpose, experiments with needle cuttings began at Kaihua Forest Farm in 1983 and the results have proved very promising.

Material and Cultivation Methods

The soil is prepared by ploughing and harrowing three times to a fine tilth, removing grass roots, and applying compost fertiliser at 1500 kg/ha. After soil preparation and making up the cutting bed, compost fertiliser (1500 kg/ha) and phosphate fertiliser (220 kg/ha) are applied. Then the bed is levelled and covered with 4 cm of sand.

Needles are harvested from coppice shoots of elite clones growing in stool-beds, aged 3 months, with diameter at shoot base of 0.4–0.5 cm. The needles, with their dormant axillary buds, are cut off the coppice shoots with a little xylem, using a single-edged razor blade. The needles are kept covered with a wet cloth and planted as soon as possible during the period

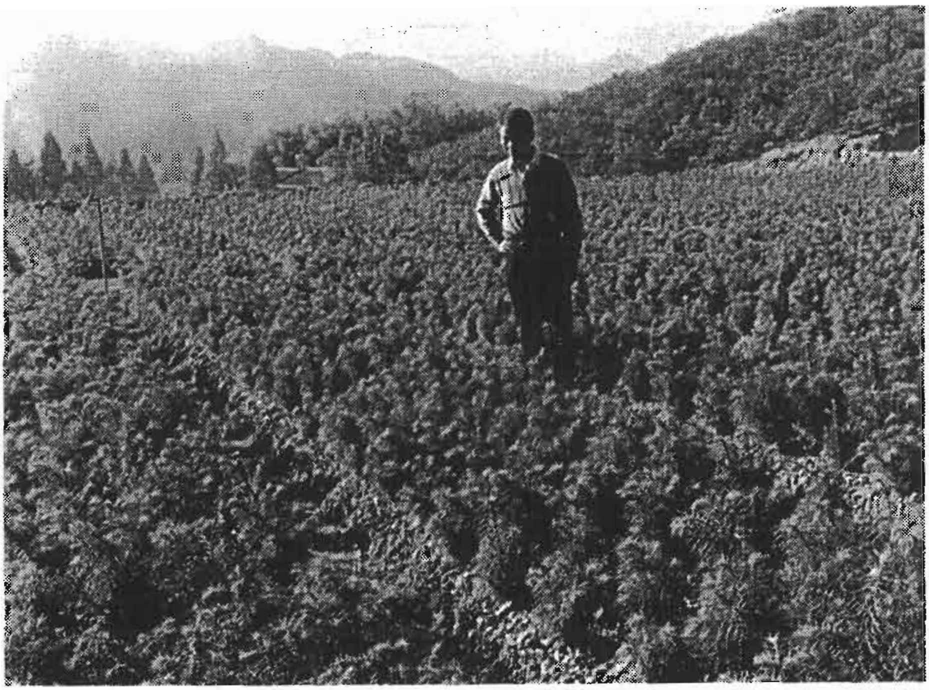

FIG. 1–Hedged stool beds, age 3 years; 60 000 stools/ha producing 2.5–3.2 million cuttings/ha (40–50 cuttings per stool).

from January to March. The spacing of the needle cuttings is 4 × 12 cm. If cut in winter, the needles should be planted with a spacing of 2.3 × 2.3 cm and placed under plastic film for promoting rooting. Transplanting to a cutting bed under shade is then required the following March, with a spacing of 4 × 13 cm.

Water sprinkling is needed every morning and evening during dry periods to maintain adequate air and soil moisture. A thin layer of human waste is applied to the bed when the needle cuttings regenerate rootlets and sprouts. In July or August, more earth should be added to maintain soil moisture. Ammonium sulphate, at 3.7 kg/ha, is applied once (in July) or twice (in July, and in August-September) during the period of rapid growth, followed by plant ash in early September, with removal of shade in early September.

Results

A nursery test was conducted in 1988 with seven clones, two replicates, 1000 cuttings per treatment. An assessment conducted in 1989 (Table 2) showed that 1 year after setting, needle cuttings had an average height of 22.1 cm, a rooting success* of 84.9%, and diameter at root collar of 0.34 cm. Both shoot cuttings and cuttings from 1-year-old cuttings had an average height of 35 cm and an average root collar diameter of 0.48 cm.

* Rooting percentage is the ratio of number of cuttings successfully rooted and growing after 1 year in the nursery to the number originally set (× 100).

TABLE 2–Clone mean growth and rooting of 1-year-old plants propagated from needles and shoot cuttings. Cuttings temporarily planted 10–12 February 1988, and transplanted 5–10 March 1989; survey date 10 November 1989.

Clone	Needle cuttings			Coppice shoot cuttings			Shoot cuttings from 1-year-old cutting		
No.	Rooting (%)	Height (cm)	Root-collar diameter (cm)	Rooting (%)	Height (cm)	Root-collar diameter (cm)	Rooting (%)	Height (cm)	Root-collar diameter (cm)
48	88	27	0.40	95	39	0.50	94	38	0.50
31	83	20	0.30	92	35	0.50	94	36	0.50
S5-5	81	23	0.35	91	35	0.50	92	35	0.50
L1	90	21	0.30	93	31	0.40	93	32	0.40
113	83	20	0.30	95	34	0.50	94	36	0.50
10	84	22	0.35	94	32	0.45	95	33	0.45
1	85	22	0.35	91	33	0.50	93	35	0.50
Mean	84.9	22.1	0.34	93	34.1	0.48	93.6	35	0.48

Another experiment conducted in 1990 showed that, at 1 year from setting, needle cuttings from different clones varied in rooting and growth. For example, Clone 1 had a rooting success of 85% and average height of 24 cm, while in Clone 116 rooting was only 20% and height was 16 cm (Table 3). Generally speaking, the wider and longer the needles of the clone, the better is the rooting percentage and height growth. In this experiment, needle cuttings from seedlings of superior families gave good performance in rooting and height growth—e.g., the yearling cuttings from seedling needles of superior family M70 had a rooting success of 85%, an average height of 28 cm, and diameter at root collar of 0.4 cm.

TABLE 3—Clone and seedlot mean growth and rooting percentage of 1-year-old needle cuttings and seedlings. Needle cuttings were planted temporarily 30 November 1990 and transplanted 20 March 1991.

Clone	Rooting (%)	Height (cm)	Diameter at root collar (cm)
44	60	21	0.30
116	20	16	0.25
1	85	24	0.35
48	85	26	0.35
M54 (seedling)	80	28	0.40
M70 (seedling)	85	28	0.40

One-year-old plants raised from needle cuttings, cuttings of coppice shoots from rooted needle cuttings, and cuttings of coppice shoots from the root collar of the same five clones were planted in trials at several sites in spring 1989. Test sites were basically identical and management was the same. Cuttings used in this test had an average height of 0.20–0.24 m and root-collar diameter of 0.4 cm. Results of the assessment conducted in 1996 at age 7 years are shown in Table 4.

At age 7 years, there were no significant differences in survival and growth rate between the three kinds of cuttings of each of the five clones, although there were significant differences between clones. Therefore, it can be concluded that it is practical to use needle cuttings for afforestation.

MAINTAINING JUVENILITY IN HEDGED STOOL-BEDS

Clonal forestry of Chinese fir is realised through initial rejuvenation, by collecting coppice cuttings from the base of a mature selected tree, and then through the establishment of hedged stool-beds. Ageing effects can build up with the growth of stool plants in the stool-bed, but if old shoots are pruned off and replaced by new shoots from the root collar, this can theoretically prevent stools from ageing and keep them in a juvenile state. In order to test the effectiveness of stool-beds in maintaining juvenility, a test with seedlings of elite families, coppice cuttings developed from the root collar, and cuttings of different propagation cycles (generations) was conducted. A randomised complete-block design was used with five replicates and 6–8 trees per row-plot in the test. The plant spacing was 2 × 2 m.

To indicate the propagation cycle, seedlings are referred to as #0 cycle, cuttings developed from shoots at the root collar collected from plus trees grown from seedlings as #1 cycle, cuttings developed from shoots collected from stool-beds of the first cycle as #2 cycle, and so on.

TABLE 4—Clone mean survival, height growth, diameter at breast height (dbh), and single-tree volume (STV) of needle cuttings, coppice shoots from needle cuttings, and coppice cuttings, age 7 years. Trial planted in March 1989 and surveyed in December 1996.

Clone No.	Needle cuttings				Coppice shoots from needle cuttings				Coppice cuttings			
	Survival (%)	Height (m)	Dbh (cm)	STV (m^3)	Survival (%)	Height (m)	Dbh (cm)	STV (m^3)	Survival (%)	Height (m)	Dbh (cm)	STV (m^3)
13	97	10.6	13.0	0.076	93	10.5	12.7	0.072	93	10.6	12.6	0.071
31	93	9.5	13.1	0.071	97	9.6	13.3	1.074	97	9.7	13.4	0.075
48	93	10.6	11.5	0.059	94	10.8	11.5	0.060	94	10.6	11.4	0.058
L1	95	9.2	11.9	0.057	93	9.5	12.1	0.060	93	9.4	11.9	0.058
X6	97	10.1	12.6	0.069	94	10.2	12.6	0.069	94	10.1	12.3	0.065
Mean	95	10.0	12.4	0.066	94	10.1	12.4	0.066	94	10.1	12.3	0.065

Field performance of seedlings of the elite family, Linin 1, and cuttings of the third propagation cycle of the same family were compared. When the stand reached age 7 years, the average height of seedlings was 8.5 m, dbh 11.0 cm, and single-tree volume (STV) 0.046 m^3, while the average height of cuttings of the third cycle was 8.6 m, dbh was 11.0 cm, and STV was 0.046 m^3. These third-cycle cuttings, therefore, showed similar growth to seedlings of the same family.

Field performance of cuttings from different cycles was compared similarly (Table 5). The test showed that there were significant differences among clones but no significant differences among propagation cycles in growth. Take Clone Kaitian 3, for example; when the stand was 4 years old, cuttings of the second cycle had an average height of 5.6 m and dbh of 7.5 cm, while cuttings of the eleventh cycle had an average height of 5.5 m and dbh of 7.4 cm. For Clone Kaitian 55, cuttings of the second cycle had an average height of 5.1 m and dbh of 6.5 cm, while the eleventh cycle cuttings had a height of 5.1 m and dbh of 6.4 cm. Similar results could be seen in clones Kaitian 1 and Kaitian 113-1. This indicated that since there were no signs of deterioration in growth among successive propagation cycles of cuttings of various clones, it is practicable to use cuttings for propagation of Chinese fir.

TABLE 5–Testing clones from different propagation cycles

Clone (No.)	Propagation cycle (year)	Age of stand (year)	Average tree height (m)	Average dbh (cm)	Average STV (m^3)
Kaitian 3	2	4	5.6	7.5	0.01596
	11		5.5	7.4	0.01535
Kaitian 55	2	4	5.1	6.5	0.01129
	11		5.1	6.4	0.01094
Average	2	4	5.4	7.0	0.01358
	11		5.3	6.9	0.01304
Kaitian 1	2	4	4.5	6.1	0.00921
	8		4.6	6.3	0.00995
Kaitian 113-1	2	4	4.6	7.0	0.01228
	8		4.4	6.8	0.01129
Average	2	4	4.6	6.6	0.01092
	8		4.5	6.6	0.01078

Cuttings developed from coppice shoots from the root collar region and from 11–12 cm up the stem in stool-beds of Clone Kaitian 1 and hybrid F43 × Xing 1 were rooted and transplanted to test position effect of shoots collected from different parts of mother trees. By age 8 years, the STV of trees from stem cuttings of Kaitian 1 was 6.3% less than that of coppice cuttings, while STV of stem cuttings of F43 × Xing1 was 4.3% less than that of coppice cuttings. Thus, using coppice cuttings gave better performance than stem cuttings.

All the above-mentioned tests suggest that using coppice cuttings strictly from the root-collar region to establish stool-beds, pruning to rejuvenate stool plants every year, and using coppice cuttings for re-establishment of stool-beds are effective for keeping stools and resulting cuttings in a juvenile state.

If eventually clones start to show signs of ageing, complete rejuvenation should be possible if coppice cuttings are collected from the base of mature trees, after felling.

SELECTION OF CLONES

Clonal selection is the key to achieving rapid growth, high yield, and good stand quality from clonal propagation. The most important element in any clonal selection programme is the choice of selection criteria (traits for selection). High selection intensity is also important, and setting standards is one way of defining selection intensity.

Selection Standards

When ortets are selected from plantation stands, experience has shown that tree height and dbh of selected trees at age 4–5 years should be 45% and 25% higher respectively, than those of surrounding trees; for 5- to 7-year-old stands, selected trees should be 30% and 25% greater in height and dbh, respectively. Single-tree volume of a plus-tree should be 50% higher than that of the five dominant trees around it.

The qualitative traits include the characteristics of the crown, branches, bark, and stem acceptability. In addition to straightness of stem, dense canopy, narrow crown, thin bark, and absence of infestation by diseases and insects, a selected tree of Chinese fir should have small secondary branches, longer and denser needles, larger numbers of lateral branches, shade-tolerant foliage, and good retention of green crown.

Selection Materials

The following genetic materials are suitable for selection of clones for clonal testing.

Elite families (including those from elite provenances)

Results from provenance trials, established widely in China by the Chinese Academy of Forestry, Beijing (Hong & Chen 1995a, b), have shown that non-local provenances have often performed better than local ones; for instance the Napo, Guangxi, provenance had a 31% higher STV than the local Kaihua provenance at Kaihua. The Napo provenance also grew very well in Jiangxi, Anhui, and other parts of Zhejiang provinces. This trend towards non-optimality of local provenances was the basis for introducing 46 selected and tested families from other areas, including Zhejiang, Guangxi, Guangdong, and Hunan, between 1982 and 1986, to add to the six local families selected from 51 Kaihua plus-tree parents. At Kaihua 232 clones have been selected from all these families. Generally speaking, the greater the variation among offspring of a family, the easier it is to select outstanding trees, and vice versa. Therefore, the best strategy may be to select only outstanding single trees from families with offspring with greater variation and to select several trees from the less variable families, to be clonally tested.

Superior inter-provenance hybrids

Inter-provenance crosses have frequently been shown to exceed the growth performance of intra-provenance crosses. They also tend to show high within-family variance, which facilitates selection of clones. Parents should be selected from superior non-local provenances, and crossed with Kaihua parents; one example was a clone whose local parent was Kaitian 3, and which exceeded its parent's STV by 34%.

Second-generation seed orchard offspring

Selection of second-generation seed orchard clones in our study was initiated in 1983, with grafting in 1984. The scions were mainly from superior trees in stands of good families and from inter-provenance hybrids. Data obtained from two sites with eight replicates showed that, at age 7, stands of seedlings from the second-generation seed orchard had an average height of 7.1 m, dbh of 10.7 cm, and STV of 0.038 m^3, representing gains of 9%, 7%, and 22% respectively over the first-generation seed orchard seedlings from the same area. Stands of offspring of these second-generation seed orchards represent good material from which to select trees for clonal testing. In addition, selection of superior trees can be carried out from 4- to 8-year-old fast-grown stands from first-generation seed orchards and from good provenances.

GAIN FROM CLONAL SELECTION

The main advantages of successful clonal forestry over other systems of delivering genetically improved stocks are increased **genetic gain** and increased **crop uniformity**. Testing and selecting the best clones for clonal afforestation and estimating their gain is the principal task in a clonal forestry programme, and demonstrating superior gains from clonal forestry *v.* seed-orchard seed is a key to acceptance of clonal forestry by forest managers. Results from such clonal trials are reported in this section.

Methods and Materials

A randomised complete-block design, with 6–8 trees per plot, 5–6 replicates, and 15–20 plots (clones) per replicate, was used in all clonal tests carried out in our study. The planting espacement was 2 × 2 or 2 × 1.7 m. The sites were generally of similar site quality within one replicate. A large-plot clone-comparison design with 36 to 64 trees per plot (6 × 6 to 8 × 8 rows) and two replicates was used in tests on effectiveness of block-planting of clones for afforestation. The check blocks were 3–5 lines with 6–8 trees per line. The area of large demonstration stands was always more than 0.33 ha with check blocks of 0.067 ha. The planting espacement was 2 × 2 m or 1.7 × 1.7 m. All seedlings in check blocks were from the Kaihua first-generation seed orchard or of a good provenance from Napo, Guangxi Province.

Gains from Clones and Seedlots from Different Improvement Levels

In order to compare the gains of different clones from various levels of improvement over a check seedlot, tests were established with cuttings at different site indices. Entries planted at all locations were: seedlings from the Kaihua first-generation seed orchard, a good open-pollinated family, Linin 1, selected from the first-generation seed orchard, and Clone Kaitian 3, selected from Linin 1. The check was a seedlot from a good provenance, Napo, Guangxi (Fig. 2); in addition, Clones 6, 11, and 5 were included in three tests. The results of successive assessments from ages 1 to 8 years are given in Fig. 3.

The amount of gain (response to selection) corresponds to the expected level of genetic improvement—that is, gain for superior clones is greater than the average of all clones > good families > the first-generation seed orchard. Gains from row-plot tests, however, are usually inflated by inter-row competition, especially in older trials. At age 9 years the superior clone Kaitian 3 had an average tree height of 9.9 m, dbh of 12.5 cm, and STV of 0.067 m^3 in a row-plot test, and these averages were 23%, 20%, and 67% higher respectively than those of the Napo, Guangxi, seedlot. However, in a monoclonal block planting, these gains were actually greater—respectively 36%, 23%, and 94%. Clone Kaitian 13 also showed considerably

FIG. 2–Row-plot clonal test. Clone Kaitian 105 (left), age 10, showing 116% gain over Napo provenance. HuaSan, Kaihua farm.

higher gains in monoclonal blocks. This phenomenon is discussed in the section on monoclonal blocks (*see* below).

The average STV of 22 clones was 0.050 m^3, a 24% increase over the check. The average STV of seedling family Linin 1 was 0.046 m^3, 14% better than the check, while the average STV of the first-generation seed orchard seedlot was the same as that of the check, 0.040 m^3. This indicates that clonal selection and propagation is an effective way to utilise the genetic variation of Chinese fir to realise maximum gains in growth rate.

Genetic Gains from Clonal Selection in Various Seedling Materials

A comparison was made between various groups of clones selected from five types of populations. These populations included: good interprovenance hybrids; second-generation clonal seed orchard offspring; selected control-pollinated, full-sib families; first-generation seed orchard offspring; and good clones selected from unimproved stands (*see* Table 6). These results represent an aggregation of results from several tests at different ages and must therefore be viewed with caution.

Gains from an average of all clones from each population are summarised in Table 6, as well as the proportions of clones selected to achieve a 40% gain in STV over the seedling

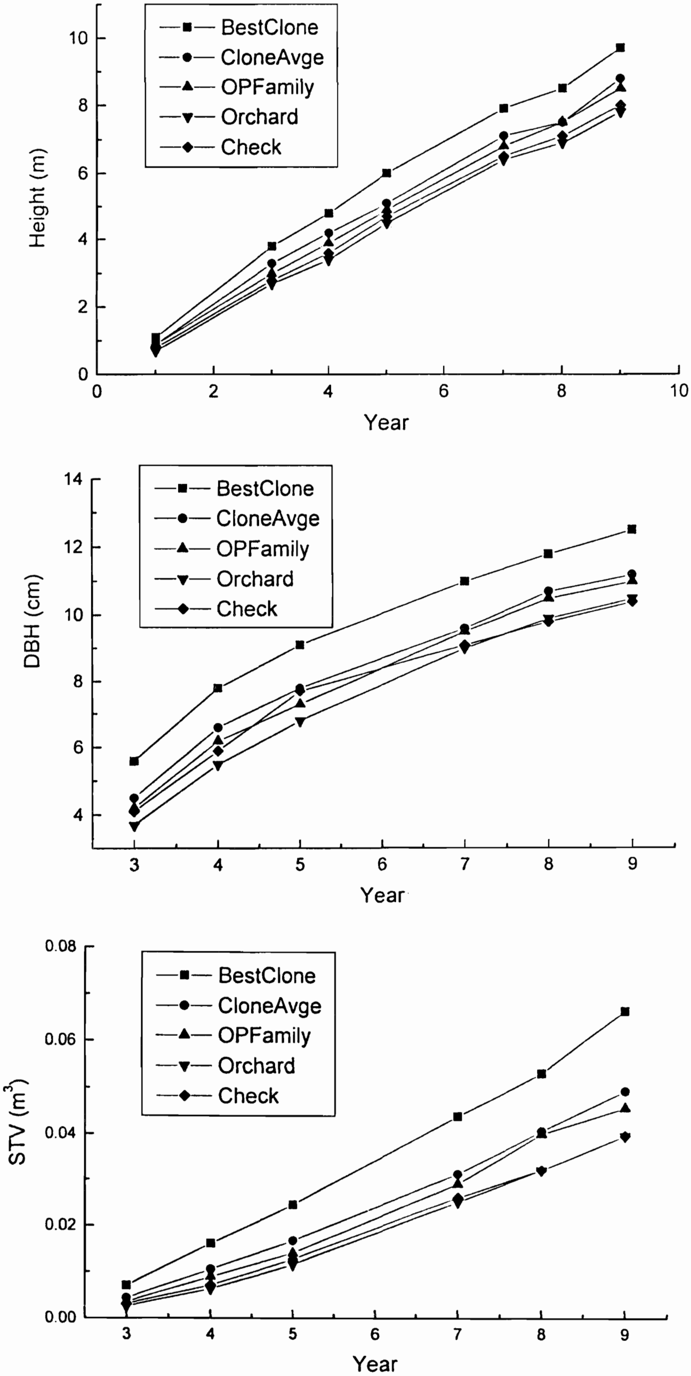

FIG. 3–Comparison of tree height, diameter at breast height (dbh), and single tree volume (STV) of selection materials of different genetic improvement levels, genetic gains resulting from clonal selection

TABLE 6–Average genetic gains from clonal selection in different seedling materials in several tests at varying ages

Selection materials	No. of clones	Test age (years)	Gain over seedling check (%)			No. clones with gains exceeding 40% over check	Clones selected
			Height	Dbh	STV		
Good interprovenance hybrid families	12	4–11	11.5	14.7	44.0	6/12	2/12
Second-generation seed-orchard offspring	5	4	17.9	11.8	40.0	2/5	1/5
Selected full-sib families	80	8–11	12.5	12.0	35.1	31/80	12/80
First-generation seed-orchard offspring	3	10	2.7	10.2	23.9	0	0
Good clones (from unimproved stands)	2	8–10	8.1	8.0	22.7	0	0

check lot of Napo, Guangxi, provenance. The clones selected from the interprovenance hybrids showed the best gains over the check of 12%, 15%, and 44% respectively in height, dbh, and STV.

Five clones selected from second-generation seed orchard offspring averaged 18%, 12%, and 40% gain in height, dbh, and STV, and when two out of the five were selected there was a gain in STV in excess of 40%.

Eighty clones, propagated from good full-sib families, showed average gains of 13%, 12%, and 35% in height, dbh, and STV and when 31 out of the 80 were selected the gain in STV exceeded 40%. Clones selected from the first-generation seed orchard offspring and other phenotypically selected clones showed much lower gains and none reached a gain of 40% in STV.

Two of the interprovenance hybrid clones had gains of 105% in STV, and 12 out of 80 clones from good families had gains averaging 84% in STV. Clonal selection can therefore be very effective, provided the base material is good and selection intensity (clones selected per clones tested) is reasonably high.

These results effectively demonstrate that intensive clonal-test selection in Chinese fir can give gains in volume production that far exceed those from seed orchards.

Gradual Screening of Clones at Successive Ages

Using the same clonal tests and data summarised in Table 6, involving 102 clones grown in 12 different tests, analyses of variance within tests indicate that there were significant differences in tree height and dbh among clones. The gains in height, dbh, and STV for 102 clones averaged 12%, 12%, and 36% over the seedling check. This was for 82 clones between ages 8 and 11 years and another 20 clones at age 4 years.

A gradual selection of clones at successive ages was made within tests, independently, first at age 4–5 years, then at age 6–7 years, and finally at age 8–12 years (*see* Fig. 4). There was significant variation in growth among clones at age 4–5 years, with clone mean height

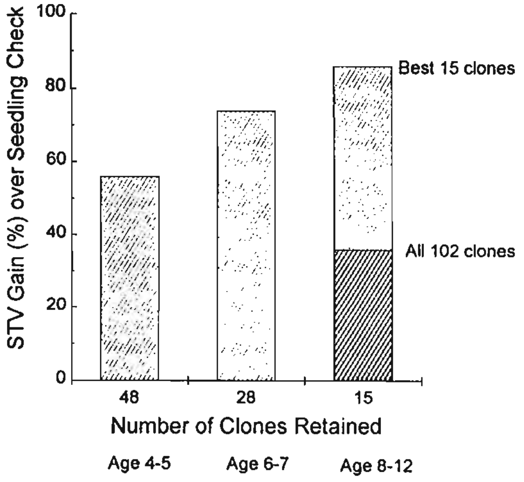

FIG. 4—Volume gains from progressive clonal selection at different ages.

varying from 4.5 to 6.5 m and clone mean dbh varying from 6.0 to 8.0 cm. It was time to conduct a first screening of clones. Taking each clonal test as a unit, 50% of the clones were rejected. In this way, a total of 48 clones were selected, and these showed an average gain of 14% in height, 19% in dbh, and 56% in STV over the check.

A second screening was conducted at age 6–7 years when the tests had average heights from 7.2 to 8.5 m and dbh from 10 to 12 cm. In the second screening 28 clones were selected and their average gains for height, dbh, and STV were 18%, 24%, and 74% over the check.

A final screening was carried out between ages 8 and 12 years when the tests had an average height of 9.5–11.5 m, and dbh of 23–25 cm. Fifteen clones were selected and these had an average gain over the check of 22% in tree height, 27% in dbh, and 86% in STV. The best clone, Kaitian 105, had an average tree height at age 10 years of 11.3 m, dbh of 16.5 cm, and STV of 0.127 m^3, which represented gains of 12%, 40%, and 116% respectively over the check. Further analysis indicated that those selected as the best clones in the final selection were always those which passed through in the first and second screening, and no clone which failed to pass the first screening was selected in the final screening.

It should be recognised that these gains were probably inflated by inter-row competition between clones, especially at the 6–7 and 8–12 year assessments.

Monoclonal-block Plantings in Afforestation

Apart from gains from selection for different traits, a major potential advantage of clonal forestry lies in the uniformity in all traits of single-clone blocks. However, with some clones there may be some additional benefits in increased volume growth in single-clone block planting *v.* single-row or single-tree mixtures of clones. Results from single-clone blocks of several clones on different sites and from large-scale, monoclonal, demonstration plantations of Chinese fir on our experimental site showed that planting single-clone blocks of some clones can result in increased volume yield (Fig. 5).

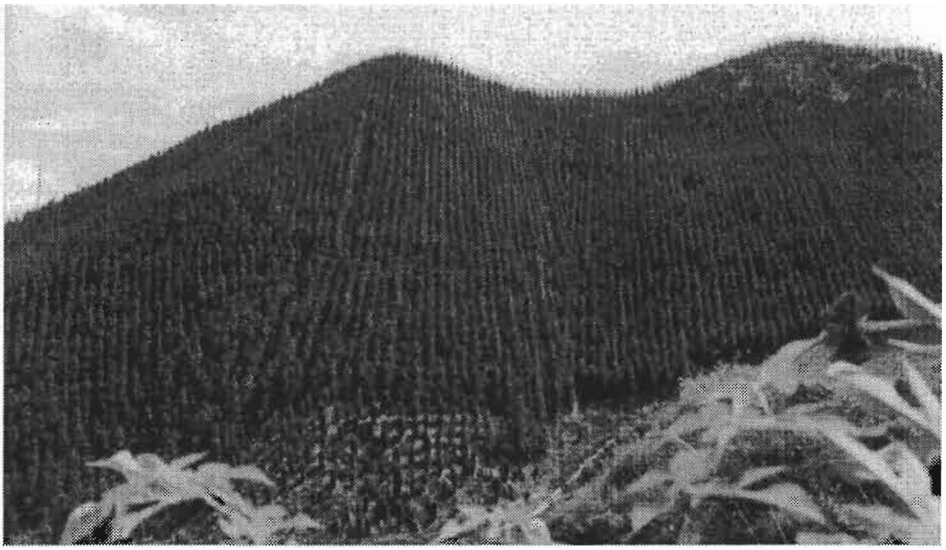

FIG. 5–Single clone block testing, age 4 years. Heng-Keng, Kaihua farm.

Take clone Kaitian 3, for example (Table 7); the average height, dbh, and volume per hectare of single-clone blocks was 11.3 m, 13.9 cm, and 284 m^3 respectively, representing gains of 36%, 23%, and 94% over the Napo provenance. In single-row plantations, clone Kaitian 3 showed only a 67% increase in tree volume per hectare over the Napo check. The monoclonal block plantations of this clone were 27% greater in volume per hectare than when planted as single-rows in mixture with other clones, a significant difference in the analysis of variance. This is apparently due to the dense canopy, narrow crown, good disease

TABLE 7–Performance of two clones and Napo provenance seedlings in monoclonal blocks *v.* row plots, age 9 years

Clone/Napo seedlings	Monoclonal blocks						Row-plots			
	No. reps	Height (m)	Dbh (cm)	Vol./ha (m^3)	Crown width (m)	Canopy closure	No. reps	Height (m)	Dbh (cm)	STV (m^3)
Kaitian 3	5	11.3	13.9	284	1.6	0.8	8	11.1	13.5	0.085
Napo seedlings	5	8.3	11.3	146	2.1	1.0	8	9.0	11.3	0.051
Gain (%)		36	23	94				23	20	67
Kaitian 13	3	11.5	12.9	251	1.9	0.95	5	11.5	12.5	0.075
Napo seedlings	3	9.0	10.7	137	2.1	1.0	5	9.2	11.0	0.049
Gain (%)		28	21	83				25	14	53
Coefficient of variation (%)										
Kaitian 3		6	11							
Napo seedlings		15	20							
Kaitian 13		7	9							
Napo seedlings		11	15							

resistance, and adaptability of Kaitian 3. When planted in a single-clone block, it had an average crown width of 1.6 m and the crown closure was 80% in the ninth year, with a coefficient of variation (CV) of 6% in tree height and 11% in dbh. The stand was sufficiently wind-permeable and trees had sufficient space for healthy growth without strong competition in the block. By contrast, the Napo provenance check lot, grown in large blocks, had an average crown width of 2.1 m, and the canopy became totally closed in the ninth year. Trees in the stand had great variability with a CV of 15% in tree height and 20% in dbh, and there was severe competition among the trees in the stand which hampered tree growth. There were strong indications of greater uniformity in the single-clone block than in the seedling-based provenance block.

Clone Kaitian 13 provides another example; it had sparse needles in the crown, and was shade-tolerant. When the canopy became closed (95% crown closure), the width of the live crown was only 1.9 m, i.e., only 16% of average tree height. It also showed strong height growth. When the clone was planted in a multi-line block, its gain in yield per hectare over the check was 30% greater than when planted in single rows. This also indicates that the use of blocks of a single clone can sometimes increase the yield per hectare.

However, this does not always occur. Our test revealed that in those clones with large crowns which are not shade-tolerant and which suffer rapid recession of the green crown, there is little difference in yield per hectare between single-clone blocks and row plantings. Clone Kaitian 48, for example, had an average height of 9.1 m, dbh of 8.8 cm, and 70% crown closure in the eighth year. Its width of live crown reached 4.1 m at this age, or 45% of the tree height. It showed a similar gain in yield per hectare to that of the row planting.

CONCLUSIONS

Chinese fir can be readily propagated by rooted cuttings taken from hedged stool-beds. Mass production of cutting planting stock is also somewhat cheaper than production of seedlings at Kaihua Forest Farm. Multiplication of 40–50 cuttings per stool is possible when the stool-bed is 3 years old, with up to 300 cuttings produced per square metre of bed.

Clones can be propagated initially from fully-juvenile shoots, induced at the base of mature trees. Continued maintenance of juvenility in stool-beds is assured by developing new shoots from the stools' root-collar region. The field tests show that there is no deterioration in growth in the plantation with successive cycles of propagation, provided cuttings are developed from coppice shoots from the root collar. Branches and old coppice shoots must be pruned from the stools to let sunlight through to promote new sprouting from the root collar.

It is also practicable to propagate Chinese fir by needle cuttings, provided these are collected from coppice shoots from the root collar. This is useful where vegetative material of a newly-selected clone is in short supply. In 8-year-old field trials, trees grown from needle cuttings showed similar growth rates to those of cuttings from stool-beds.

The clonal tests carried out so far show that clonal selection followed by mass propagation (clonal forestry), is an efficient way to utilise the various components of genetic variance to get maximum gain in yield per hectare. In order to increase the effectiveness of clonal selection, the existing tree improvement programme must be fully utilised; choosing the best genetic material as a starting point increases the potential gains from clonal selection. At present selected families from good parents, interprovenance hybrids, and second-generation seed orchard offspring are providing good materials for selection.

The best clones tend to come from superior families with the highest within-family variances. If there is little variance within-family or between-families it is better to select several clones for testing. It is possible to select fast-grown clones from inter-provenance hybrids of selected parents, especially those from widely-separated geographical locations.

In applying clonal forestry with Chinese fir, it is practicable to carry out clonal selection by gradual screening in successive years. Screening may be done at age 5 years to eliminate about 50% of the clones, then at age 6–7 years to eliminate another 20%. At age 8–12 years (average height 9.5–11.5 m) selection should leave about 15% of the clones, resulting in a gain of 86% in STV over the check group. Up to the present, Kaihua County has planted 2700 ha of clones, selected by at least one screening, and significant economic and social benefits have been achieved.

Generally speaking, those clones with dense canopies and good adaptability, and which are shade-tolerant, dominant in height growth, and with low height of green crown will show increased yield per hectare if they are planted in large single-clone blocks. Under these conditions they show little variation and little assertion of dominance within the stand.

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