which make them interesting for introduction into a climate such as we have in New Zealand. In the family of Caricaceae, a number of species exist in the mountains of Ecuador which have now been established in New Zealand as commercial cultivars. Bromeliads and orchids are particularly striking in this altitude range.

Above 2700m to 4000m the vegetation becomes more sparse. Such areas are termed the Páramo. Often shrouded in mist and cold, heathlike plants exist with a stature no more than 2 metres. The Family Compositae is very common and so are ferns and lichens. One fruiting plant, *Vaccinium floribundum*, carries numerous small berries, refreshing in flavour.

The botany of the west coast region of South America is still incomplete. The rapid disappearance of the native vegetation offers a challenge for those adventurous enough to visit these areas. Plant life in South America is extremely rich and varied.

VEGETATIVE PROPAGATION OF RADIATA PINE

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Abstract. Systems used for vegetative propagation of *Pinus radiata* (radiata pine) in New Zealand are briefly described. Mature trees are propagated by cuttings or grafts for the establishment of archives and seed orchards. Several propagation techniques are being developed for multiplication of scarce seed of the best genetic material. Options include collection of cuttings from young plantation trees, manipulation of seedlings in nursery stool beds, and micropropagation.

INTRODUCTION

Radiata pine plantations traditionally have been established using seedlings. This programme has used up to 5000 kg of seed each year, with over ¾ of it being improved seed from open-pollinated seed orchards.

Further significant improvements in tree quality can be made using seed from controlled pollinations between the best parents (12). It would be feasible, but logistically difficult, to produce all New Zealand's requirements by controlled pollinations. An alternative method is to combine a programme of controlled pollination with some form of vegetative propagation (4). Rapid advances are being made in propagation techniques for juvenile planting stock, including collection of cuttings from plantation trees of improved seed origin,

manipulation of young seedlings in the nursery beds as seedling stools, and micropropagation (8).

A. VEGETATIVE PROPAGATION OF OLD MATERIAL FOR SEED ORCHARDS AND ARCHIVES

Grafts and cuttings are used for cloning physiologically old (10 years or older) radiata pine to establish seed orchards and clonal archives. Cuttings are preferred because of the problem grafts often present with delayed incompatibility. However, cuttings taken from old parent ortets rarely root satisfactorily, necessitating grafting as a first step in propagation procedures for newly-selected trees.

Bud scions are taken in winter from parent ortets for grafting, and the grafts used for establishing temporary clonal orchards (usually hedged), or for initiating new seed orchards. Once the grafts are large enough for repropagation (3 years after planting), they are used as a source of cuttings for setting up permanent archives and seed orchards.

For cutting production, the current season's shoots are cut back in late summer (mid-February) to where foliage is dense and fully developed (topping). In March, 3 to 4 weeks after topping, when the cuttings have developed small needle fascicle buds, they are ringbarked 50 to 150 mm below the terminal topping. Then in April, 4 to 6 weeks after ringbarking, the cuttings are collected and set in polythene tunnels which maintain a temperature of 15 to 28°C during daylight hours and a humidity of 70 to 100%. If the prescribed propagation system is adhered to, 70% of the cuttings strike successfully and develop balanced root systems.

B. VEGETATIVE PROPAGATION OF JUVENILE MATERIAL FOR PLANTATION ESTABLISHMENT

(1) *Vegetative propagation using field cuttings*

Cuttings can be readily propagated from young radiata pine trees in the forest. Plantations best suited to cutting collection are those established with seedlings from special seedlots, collected from the best seed orchard clones (3) or from control-pollinated crosses. Collection from field trees also allows some selection for vigour and form of the parent ortet.

Cutting material should have dense, fully elongated healthy needles, with a cutting length between 100 and 150 mm, and a minimum diameter of 6 mm. Collection is made during the period of slowest growth (in Rotorua from late April to late June) and the cuttings are set outside in raised nursery beds. Overhead irrigation is necessary during warm or dry windy weather, particularly during the first few weeks

after setting. Rooting occurs in the spring following setting, with acceptable rooting of about 80% from 3-year-old ortets. The cuttings are later conditioned by undercutting, lateral root pruning and wrenching, and are ready for lifting one year after setting.

Field collection of stem cuttings is time consuming and expensive, as it involves travel, and only a few cuttings can be collected from each tree. Cuttings from older trees have advantages in that ortets can be selected for desired characteristics, and malformation is greatly reduced, but they do have reduced initial diameter growth and are not always easily rooted.

(2) *Vegetative propagation of juvenile material using nursery stool beds*

(a) *Seedling pruning*: Seed is sown in spring (September/early October). In February, when the seedlings are 100 to 180 mm tall, they are topped 5 mm above the highest side shoot. Several side shoots then develop into stem cuttings. Cuttings 50 to 100 mm long can be collected and set in winter either in open beds or open containers. Any remaining lengths of new leaders can also be collected and set. This method gives a multiplication factor of up to eight. Open bed cuttings are conditioned as for field collected cuttings and are ready for planting the following winter. Containerised cuttings are grown on a low nutrient regime to produce woody stemmed plants 100 to 200 mm tall. Rooting percentages for these types of stem cuttings exceeds 90%.

(b) *Seedling pinning down*: Various techniques are being developed to raise elongated fascicle shoots suitable for open bed or container setting. The two most promising options are:

(i) *Open-bed cuttings*: Seed is sown in September. Stock plants are grown for 14 months to about 1 metre tall. They are then topped to about 750 mm to remove soft top growth, and pinned down to the ground. The resulting fascicle shoots are thinned to 30 mm apart along the seedling stem after 4 to 6 weeks. By May, 20 months after sowing, the seedlings have produced shoots 100 to 150 mm in length. These shoots are collected and set in outside nursery beds. The multiplication rate is 30 to 40× if only first-order cuttings are collected, or up to 80× if two cuttings are collected per shoot. The stool beds can be used for more than one year, by saving the shoot closest to the root system for pinning down the following November.

(ii) *Container cuttings*: Seed is sown in early spring (September). Six months later, in March, when seedlings are 100 to 200 mm tall, they are topped and pinned down. The develop-

ing fascicle shoots are left unthinned and are collected in June, 9 months from sowing, and set in containers outdoors. Cuttings are ready for planting in February-March. The average multiplication rate is 17×, with rooting success of 99%.

C. MICROPROPAGATION

Micropropagation methods have been developed for a variety of explants, including embryos, cotyledons, and seedling shoot tips (2,6,9). Amongst the many steps involved are shoot initiation, shoot elongation, shoot multiplication, and rooting.

Shoots can be initiated from: excised embryos, cotyledons from 5- to 7-day-old germinated seeds, or induced fascicle shoots from 9-month-old seedlings. After sterilisation, all explants are cultured on a shoot-inducing medium containing cytokinin. The shoots are then placed on an elongation medium without cytokinin. Several transfers (two to six) are necessary to get fully elongated shoots of about 15 to 20 mm. At each transfer clumps of shoots are cut into smaller pieces and the newly cut surface placed in contact with the medium. Small shoots can be multiplied in culture to build up numbers of a clone by topping and allowing new side shoots to grow out, or by placing shoots on a medium with cytokinin. Shoots can also be cold-stored in culture at any stage of elongation, thereby arresting growth. Growth resumes when the shoots are replaced in the controlled environment chamber under normal culture conditions.

For root initiation, shoots are first given a 5-day auxin treatment, then planted in a non-sterile potting mix in trays and kept in a high humidity chamber. After rooting, the plantlets are transferred to a plastic tent in the glasshouse, hardened off, and lined out in nursery beds under shade cloth. The plantlets then receive the standard nursery treatments given to seedlings. From auxin treatment of shoots to planting out of micropropagated stock takes 12 months.

The multiplication rate from micropropagation depends on the time *in vitro*. A 1000 × multiplication is feasible for a propagation period of 22 months, from seed to plantlets at the nursery gate, but higher multiplication rates would be possible given a longer time, with *in vitro* stages of remultiplication.

By holding micropropagated shoots in cold storage (1) it may be possible to test clones in the field while ramets are kept in juvenile state in the cold store, rather than growing in hedged archives, as previously described (7,10).

DISCUSSION

There are two main reasons for the upsurge of interest in vegetative propagation of radiata pine in New Zealand. Firstly,

the tree breeding programme at the Forest Research Institute is continually producing control-pollinated seed, in limited quantities, from the best available parents. Progeny from these seedlots are measurably superior to those from open-pollinated seed orchards. With vegetative propagation, progeny from this scarce seed can be made more widely available, thereby permitting greater areas of forest to be planted with the best genetic stock. Secondly, the improved form of cuttings from older ortets has become apparent from field trials (11,13), and this has led to a demand for these cuttings (3). As a consequence of the improved genetic quality of the seed stock, and the improved form associated with age, cuttings can be planted confidently at comparatively wide spacing. Although the cost per plant is higher than for seedlings, the cost per hectare appears very competitive.

There is a wide variation in multiplication rate, time taken to produce cuttings, and cost of the various forms of vegetative propagation (Table 1). The method used will depend on the relative importance of these three factors.

One of the easiest methods for multiplication of seedlings is top pruning, using nursery stool beds. Cuttings can be set bare-root or in containers, and the time in the nursery is less than two years, although the multiplication rate is low. A higher multiplication rate can be obtained from stool beds using the pinning-down method, but the cuttings must be set in containers, unless the time in the nursery is extended to three growing seasons. However, the multiplication rate is more than doubled with an extra year in the nursery and the stool beds can be used for more than one crop of cuttings.

Table 1. Summary of approximate costs for various propagation options.

Method	Multiplication rate	Bare-root or containers	Minimum time in nursery (months)			Cost (NZ$/1000) plants
			Stool bed	Rooting	Total	
Seedlings	1	B	—	—	10	50
Field	3-5	B	—	12	12	160
Topped stools	8	B	9	12	21	77
		C	9	8	17	90
Pinned down stools	17	C	10	8	18	87
Pinned down stools	80	B	20	12	32	70
Micro-propagation	1000	B	—	11	22	450

Recently research interest has focused on propagation from control-pollinated seed of genetically improved families. The original idea of using rooted cuttings for plantation forestry was to use clones that had been field tested (4,5,7,10,13), but there were found to be several problems, the main difficulty being that of maintaining hedges in a juvenile state. Micropropagation, and cold storage of ramets as micropropagated shoots, could be a viable alternative. For multiplication of control-pollinated families, micropropagation is very expensive compared with other propagation methods (Table 1). Either the labour cost must be significantly reduced or alternative techniques (e.g., somatic embryogenesis) need to be developed if this method is tto be competitive. Besides the high cost, there can be problems achieving a balanced root system on plantlets. Both problems could be resolved if, after initial micropropagation from seed, plantlets were lined out as nursery stools, pinned down, and used as a source of stem cuttings for open-bed or container setting (8). If micropropagated plantlets cost $450/1000 to produce, this would add only $5.60/1000 to the cost of the resulting cuttings, assuming an 80× multiplication rate from the stools.

CONCLUSIONS

With seed of improved genetic quality becoming available from controlled crosses between progeny-tested parents, vegetative propagation is seen as a useful way of extending this scarce seed. Several methods of propagation can be used, but the most promising involve use of nursery stool beds, by topping and pinning down seedlings to produce cutting material that can be set in the open nursery bed or in containers.

If clonal forestry is judged desirable for gaining benefits of further genetic improvement, then use of micropropagation techniques may allow clonal testing in the field while maintaining clones in a juvenile state in cold storage as micropropagated shoots.

Cuttings will be used more widely for planting radiata pine in the future as these new propagation methods are developed and adopted by forest nurseries.

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LITERATURE CITED

1. Aitken-Christie, J. 1984. Micropropagation of *Pinus radiata*. *The Plant Propagator 30(3)*: 9-11.
2. Aitken-Christie, J., and T.A. Thorpe 1984. Clonal propagation of Gymnosperms. *In* Cell culture and Somatic Cell Genetics of Plants. Vol. 1. (I.K. Vasil ed.). Academic Press, Inc. pp. 82-95.
3. Arnold, R. and J.A. Gleed. 1985. Raising and managing radiata pine vegetative cuttings for production forests. *Austral. For.* 48(3):199-206.
4. Burdon, R.D. 1982. The roles and optimal place of vegetative propagation in tree breeding strategies. Proc. IUFRO Joint Meeting of Working Parties on Genetics about Breeding Strategies Including Multiclonal Varieties: 66-83.
5. Fielding, J.M. 1970. Trees grown from cuttings compared with trees grown from seed (*Pinus radiata* D. Don). *Silvae Genetic. 19*: 54-63.
6. Horgan, K., and J. Aitken. 1981. Reliable plantlet formation from embryos and seedling shoot tips of radiata pine. *Physiol. Plant* 53: 170-175.
7. Libby, W.J., A.G. Brown, and J.M. Fielding, 1972. Effects of hedging radiata pine on production, rooting, and early growth of cuttings. *N.Z.J. For. Sci. 2(2)*: 263-283.
8. Menzies, M.I., T. Faulds, M.G. Dibley, and J. Aitken-Christie. 1985. Vegetative propagation of radiata pine in New Zealand. Paper presented at the International Symposium on Nursery Management Practices for the Southern Pines. Montgomery, Alabama, USA.
9. Smith, D.R. 1985. Micropropagation of forest trees: *Pinus radiata* in New Zealand as a model system. *In* Micropropagation of Fruit and Forest Trees. (Y.P.S. Bajaj. Springer Verlag, ed.) (in press).
10. Thulin, I.J., and T. Faulds. 1968. The use of cuttings in the breeding and afforestation of Pinus radiata. N.Z.J. For. 13(1): 66-77.
11. West, G.G. 1984. Establishment requirements of *Pinus radiata* cuttings and seedlings compared. *N.Z.J. For. Sci. 14(1)*: 41-52.
12. Wilcox, M.D., C.J.A. Shelbourne and A. Firth. 1975. General and specific combining ability in eight selected clones of radiata pine. *N.Z.J. For. Sci.* 5*(2)*: 219-225.
13. Wilcox, M.D., I.J. Thulin and T.G. Vincent. 1976. Selection of *Pinus radiata* clones in New Zealand for planting from cuttings. *N.Z.J. For. 21(2)*: 239-247.