ARTIFICIAL ESTABLISHMENT OF NEW ZEALAND KAURI AT WAIPOUA

F. T. MORRISON AND R. C. LLOYD*

SYNOPSIS

A satisfactory nursery technique for kauri (Agathis australis) *has been developed. Current trials aim at streamlining the various phases.*

Blood and bone and superphosphate separately have increased the size of nursery stock but the effect on planted kauri is not so apparent.

A kauri seed orchard has been established at Waipoua Forest and others are planned elsewhere in the Auckland Conservancy of the Forest Service.

The most important factor in the planting phase is soil condition rather than nutrient content. Friable well-drained soils of low fertility are preferable to comparatively fertile, normally compacted clays. Early planting (April) is an advantage. A light cover crop is desirable but this must be either entirely removed or drastically reduced within 5 years of planting.

INTRODUCTION

Attempts to manage kauri stands depend initially on developing methods of establishment. Certain aspects have been studied in detail, and suitable methods of nursery production and planting have been developed. Stands can now be satisfactorily established for further silvicultural studies. However, the methods are relatively costly and need to be further developed for operational use. Work is proceeding with this in view. This paper brings together, in a concise form, results of research carried out over a period of 18 years.

NURSERY PRACTICE

Seed

Seed is collected from 94 selected numbered trees in Waipoua Forest. Most of the trees are immature, ranging from 29 to 66 cm in diameter and from 15 to 27 m in height. Aluminium ladders are used for climbing. Formerly seed was gathered from large mature trees, but only in the younger trees can desirable, superior form and vigour be detected.

The average number of seed per kg is about 35,000 with a maximum of 101,000. Seedlots from separate trees revealed

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*This paper was written by the late F. T. Morrison in 1965 while he was a Senior Forester, Kaikohe district, New Zealand Forest Service. It was updated in 1971 by R. C. Lloyd, the present Kauri officer for the Auckland Conservancy.

that one tree yielded seed of much larger size, running at 20,000 to 24,000 per kg. Correspondingly large seedlings were produced from this lot and, although the size differential is not maintained on a long-term basis, the added early vigour can be an important advantage in contending with unchecked weed growth on the planting site. Seed from this tree usually germinates several days ahead of seed from other trees. Laboratory germination percentages are also consistently high. As a general rule, large cones produce larger seeds which are usually of high viability.

A trial with seed from a single, open-grown planted kauri about 30 years old has shown that nursery germination differs in relation to the position of cones in the crown. There is also a trend in numbers of cones in different sections of the crown. Both of these are shown in Table 1.

TABLE 1: CONE POSITION IN CROWN RELATED TO NURSERY GERMINATION

Position of Cones in Crown	*Nursery Germination (%)*	*No. of Cones*
Top third of green crown	24	139
Middle third green crown	31	48
Lower third green crown	47	23

Kauri seedlings have either red or green cotyledons, in more or less equal proportions. Those with green cotyledons are more vigorous initially but this advantage tends to disappear, along with the colour difference, with increasing age. All kauris are ultimately green-leaved. According to Peterson (1963) the red colour is due to the presence of rhodoxanthin, a red carotenoid pigment which has previously been recorded in the leaves of a number of genera of gymnosperms.

Cones should be collected before they break up on the tree which usually occurs over a full fortnight; cones are therefore best picked when scales from the early ripened cones are first observed on the ground. At Waipoua Forest this is generally early in March but can be a little earlier. A comparatively low germination was obtained from an experimental collection made in mid-January.

No artificial heat is required for extraction since cones will break up naturally indoors within 7 days. Extraction in sunlight is likely to be impeded by the adhesive effect of abnormal gum exudation. Separation of sound and unsound seed can be achieved by immersion in cold water for up to 48 hours, normally 24 hours. Sound seed will sink. De-winging should be carried out before sowing.

During the last 30 years there have been annual seed crops but better yields appear to occur every third year on average. In 1964, which was a poor year, it was necessary to extend collection to unnumbered trees of good form.

The rapid deterioration of seed under normal conditions makes it imperative to sow as soon as possible after collection.

If seed from superior sources and good seed years is to be best employed and the collection costs kept down, an effective means of storage is a necessity. Mirams (1957) has shown that a relative humidity of less than 50% and a low temperature are important for retention of seed viability. These findings are confirmed by Preest (1962) who found that germination drops rapidly and is nil or nearly nil after 16 months of storage under room temperature conditions with temperatures exceeding 10° C and a moisture content of 10% or more of dead weight. However, with moisture content reduced to 6% and temperatures to 5° C or 10° C, germination is still above 80% after 4 years' storage. At moisture content of 15% or more, germination after 16 months is almost non-existent, irrespective of storage temperature (Appendix 1). Moisture content is kept constant by drying to the desired weight and sealing in polythene bags.

Seed Treatment and Sowing

Trials at Waipoua have shown that, to improve germination, seeds should be treated with fungicides. Control plots gave germination of 38.5%. Improvements were obtained with chloranil (41%), captan (54%) and thiram (57%). The last is now used as a standard procedure.

Water rather than latex should be used as an adhesive, as the latter may cause prolonged testae retention possibly leading to damping off.

Raised beds 0.8 or 1.2 m wide are recommended. Seed should be sown in drills 0.1 cm deep, 20 to 30 cm apart at a density to produce five to six seedlings per 30 cm. Seed should be covered lightly. Beds should be shaded with light grade hessian on frames, to be removed when germination is complete and replaced with covers providing one-third direct light for the first year and two-thirds for the second and most of the third year. For this, aluminium slats 5 cm wide on wooden frames have been found satisfactory. In the third year, frames are gradually removed from February-March onwards, taking into account weather conditions. Should a fourth nursery year be necessary, no shade is required. Frames fitted with legs can be raised as seedling height increases.

Weed Control

Usually kauri germination precedes that of weeds, but if germination is slow petroleum weedicide (aromatic content 18%) can be used as a pre-emergence spray.

The same formulation should be used as a post-emergence treatment.

If a tractor-mounted spray rig is used, the seedbed frames must first be removed. However, if a knapsack pump is used, frames need be raised on only one side.

Wrenching

Wrenching is carried out by a tractor-mounted blade; lateral roots are cut with a spade where line sowing is used.

Experimental broadcast sowings have shown that laterals cannot be cut and a straggling root system tends to develop during the three-year nursery period.

Special Techniques

A number of special nursery techniques have been tried. Tubing was introduced from Queensland where it is considered the key factor to the successful artificial establishment of *Agathis brownii*. Its use gives slightly increased survival of kauri at Waipoua but its extra cost relative to planting open-rooted stock is considered to outweigh any benefit gained. It is possible that a root-rotting fungus associated with the nursery soil component of the tubing mixture has induced mortality by partially destroying roots, leaving sufficient for development in normal weather conditions, but insufficient for drought conditions. Sterilization of the tubing mixture might eliminate the root-rotting fungus but would also add to the cost.

Because of its cheapness, the soil block method would offer a possible alternative to the conventional nursery technique if growth problems in the third year could be overcome or if stock of adequate size could be raised in 2 years. It has not proved possible so far to grow satisfactory three-year stock and the seedlings produced are generally rather small. Root-rotting fungi may again be responsible but sterilization of the soil block mixture may overcome this.

The blocks are constructed by machine. The mixture used comprises one part taraire (*Beilschmiedia tarairi*) leaf mould, two parts of sieved nursery soil plus small amounts of semi-decomposed pine needles of any exotic species which act as a binding agent. Blood and bone is added to each block at a rate of 3.5 g.

Three sound seeds are sown in each block direct, or cotyledonary seedlings raised in beds or boxes are pricked into blocks (one seedling per block). Only one seedling from the direct sowing is retained.

Blocks are set out in a shallow box 46 cm × 24 cm × 8 cm with sides raised slightly higher than the surface. The spaces between the blocks are filled in with sawdust or duff which will also cover the upper surfaces of the blocks, preventing excessive erosion and loss of moisture. Shading similar to that used on the seedbeds should be erected. Frequent watering is necessary in periods of prolonged drought.

Soil blocks have some advantages: seedbeds are not required, wrenching is unnecessary, weeding is reduced, and seedling roots are protected at time of planting. There are, however, disadvantages: it is questionable whether the blocks will last three years without breaking up. The incorporation of extra fibrous material might offset this tendency; also blocks have to be watered more frequently than normal seedbeds.

The Dunemann system was first tried at Waipoua in 1954. This method involves raising seedlings in a bed of decomposing pine litter. While good initial results were obtained, the rooting system developed was irregular and not conducive to survival in the field. The method has been abandoned.

Soil Treatment and Pathology

In the past there have been heavy losses of nursery seedlings caused by the root rotting fungus *Phytophthora cinnamomi*. For example, only 4,000 seedlings were fit for planting out of an original lot of 22,000 raised from a 1955 sowing.

Poor nursery drainage, occasional flooding from an adjoining river, and shade from nearby indigenous forest on part of the nursery led to conditions especially favourable for development of the soil fungus.

A soil sterilization trial has had beneficial effects on seedling survivals and size. Sterilization was carried out before sowing in autumn 1958. Table 2 shows the effect on resultant three-year stock.

TABLE 2: COMPARISON OF GROWTH USING STERILIZING AGENTS

Sterilizing Agent	*Average Height Seedlings (cm)*	*Seedlings >70 cm in Height (%)*	*Tallest Individual Seedling (cm)*
Chloropicrin	31.7	30	85.0
Formalin	22.8	9	78.7
Control	17.0	1	58.7

Much the same results were obtained by incorporating 5 cm of taraire leaf mould in the top 15 cm of seedbeds before sowing. It is almost certain that the leaf mould improved soil aeration and texture and encouraged the development of beneficial soil micro-organisms.

The addition of readily available leaf mould has been adopted as standard practice rather than relying on the more expensive soil sterilants.

Effects of Fertilizers

A nursery experiment has shown that 44 to 46% superphosphate applied at the rate of 135 g/m^2, together with ammonium sulphate at 70 g/m^2, and superphosphate alone at 135 g/m^2 significantly increased the total weight of lined-out kauri. The effects of addition of lime were inconclusive.

Small-scale trials were conducted using copper sulphate, flowers of sulphur, sodium nitrate, manganese chloride and potassium chloride. None of these had any obvious effect on seedling growth.

The incorporation of 3.5 g of blood and bone in tubes and soil blocks increases seedling size.

Insect Pests and their Control

Among the more important insect pests are the larval forms of the tortricids *Epichorista persecta* and *Ctenopseustris* *obliquana*, the semi-looper *Declana floccosa*, and the looper *Selidosema suavis*. All these defoliators are effectively controlled with a lead arsenate spray.

The black Australian cricket (*Gryllus servillei*) is likely to destroy germinating seed and is controlled by baits comprising 50% DDT, bran and molasses.

A spray of wettable 50% DDT is sufficient to check the garden weevil (*Phlyctenus callosus*) which has appeared in the seed orchard and to a lesser degree in the nursery.

FUTURE SEED SUPPLIES AND BREEDING EXPERIMENTS

The introduction of a successful tip-cleft grafting method has meant that it has been possible to establish a kauri seed orchard by grafting scions from superior seed bearers on to young stock.

Some 350 specimens have been established at Waipoua since 1956, and token quantities of viable seed have already been obtained. However, it will be 10 to 20 years before appreciable quantities can be gathered. By then it is expected that the less satisfactory specimens will have revealed themselves and the number of grafted trees remaining will be comparatively modest. The present considerable cost of kauri seed (about $30 per kg) is due predominantly to the cost of collection which should be considerably reduced by the establishment of easily accessible orchards.

The danger of confining the work to Waipoua Forest and obtaining grafting material from only one location has been recognized, and it is intended to set up at least one other seed orchard at a more easterly location, using seed-bearing trees of superior type from outside Waipoua as sources.

Few useful results have been obtained from other tree-breeding experiments. Root grafting and air layering proved unsuccessful; tip-cleft grafting has in any case largely taken over their intended function. Attempts to cross-fertilize *Agathis australis* with *A. brownii* (*robusta*) (South Queensland kauri) and *A. palmerstoni* (North Queensland kauri) failed, but the failure is not completely conclusive as the pollen used in the experiment was not in good condition. *Agathis brownii* scions have been successfully tip-cleft grafted on to *A. australis* wilding stock.

PLANTING OF KAURI

Site Conditions, Preparation and Planting

At Waipoua Forest most experimental plantings have been applied to broadleaved forest (12 to 18 m in height) sites where kauri has not occurred as a previous crop—at least not in recent years. Of the several techniques used, planting in groups of 5 or 13 trees, aiming at a final crop of 200 to 250 stems per hectare, seems the most promising. Advantage is taken of natural gaps in the forest canopy, clearing being kept to a minimum necessary to obtain an essential light tunnel vertically above the planted group. Trees surrounding a group are killed by girdling the season after planting if they are likely to crowd the kauri.

Other methods involving the entire removal of the greater part of the forest cover such as clearfelling, strip felling, and girdling have at least one serious defect as they allow a copious invasion of secondary species and exotic weeds. Among the most troublesome of such invaders are wineberry (*Aristotelia serrata*) and the indigenous bent grass (*Oplismenus undulatifolius*), which often smother seedlings under a dense mat of vegetation.

Attempts to establish kauri under exotic forest species have been generally successful, particularly where group plantings have been carried out.

Satisfactory survival and growth is obtained in the open, but light to moderate cover—*e.g.*, manuka (*Leptospermum scoparium,*), kanuka (*L. ericoides*)—or secondary indigenous species 3 to 5 m in height is desirable. The cover must be drastically reduced or entirely removed approximately 5 years after planting.

The key factors to success in the establishment phase of kauri are undoubtedly soil texture and condition. Growth is usually enhanced in soils of loose, friable structure, irrespective of their nutritional characteristics. Foliar analyses carried out by N.Z. Forest Research Institute yielded almost identical results from samples collected from vigorous trees growing in low fertility friable soils and comparatively slow-growing specimens in compacted clays of medium fertility. In its young stages, naturally established kauri have a well-developed taproot and it is possible that root penetration and development in free soils is an important aspect of growth. A study of planted kauri has revealed that well-grown specimens also have strong taproots.

Establishment is possible where conditions are less than optimum, but costs are comparatively high. For compacted soils (for example, the general run of clay soils at Waipoua), deep-pitting is recommended at least 3 months before planting to allow beneficial soil weathering. The pits are 30 cm square dug out to spade depth, the soil 15 cm below the bottom being further disturbed. The soil is then replaced and the seedling planted by hand in the centre. When planting with soil block or tubed stock, the soil around the seedlings should be fractured (but not disintegrated) to help offset a tendency to shrink from the soil in the pits during dry weather. The effects on survival may be judged from the results of a trial near Waipoua Forest headquarters where survival of pitted kauri was 54% against 29% in stock planted by conventional methods. A further trial in an area where broadleaved cover had been removed, conducted in 1957 and 1958, resulted in an overall survival of 93% in deep pits, and only 78% for conventional planting methods.

Pitting is a slow method of planting but can be mechanized by the use of post-hole diggers.

The results of trials conducted in 1958 in which soil was broken by a ripper were encouraging and survival was improved, 100% as against 88% for an untreated area. The ripper used was a 10 cm × 3 cm × 137 cm long piece of silver steel attached to the front of a tractor blade and projecting below the blade by 70 cm. It produced a narrow trench similar to that made by a mole plough.

This method is more economical than deep-pitting over extensive areas and can be combined with crushing.

It had been usual to plant kauri in July and August. In a trial comparing planting in April and July, carried out in 1958, survival for April planting was 75%, and height growth in the first year was 15 cm. This was greatly superior to July planting, which gave a survival of 60% and mean height growth of only 4.8 cm.

Autumn planting was further supported in 1959 with a 94% survival from an April planting compared with 70% from an August planting. It is highly probable that planted kauri is adversely affected by poor soil condition and low soil temperatures following prevailing winter rains, particularly on clay soils under forest cover. On the other hand, soils are comparatively dry in the late autumn and still retain sufficient heat to promote active root growth before the onset of winter conditions.

Effects of Fertilizers on Planted Kauri

Although better results are generally obtained from the incorporation of fertilizers and blood and bone in planting pits, survival and growth have not been significantly increased. Table 3 sets out results obtained from group-planted kauri (1961) in compartment 58, Waipoua, in a clay soil.

TABLE 3: EFFECT OF FERTILIZERS ON PLANTED KAURI

Fertilizer	*Quantities applied (g)* *In Planting Pit (a)*	*On Ground Surface (b)*	*Survival (%)* *(a)*	*(b)*
Superphosphate (44-46%)	60	110	72	59
Blood and bone	60	110	74	55
"Nitrochalk" (20.5% N)	60	110	55	53
Controls	—	—	65	66

Other trials show a slight increase in height following the application of 90 g of "Nitrochalk" (20.5% N) per tree to the surface of a light sandy soil, while at Raetea Forest, on a clay soil, a similar result was obtained by applying cow manure to the planting pit.

Among the macro-elements necessary to plant growth, nitrogen and phosphorus are generally the least abundant in Northland soils. It has been shown by Peterson (1962) that it is precisely these elements that the kauri requires at comparatively low levels for maximum growth. It is therefore not surprising that responses to the more common fertilizers have not been great. Such effects as have been observed could well be due almost entirely to changes brought about in the physical condition of the soil. Table 4 gives the concentrations

TABLE 4: PERCENTAGE DRY WEIGHT ON N AND P AT MAXIMUM GROWTH

Element	*Agathis australis*	*Picea abies*	*Betula verrucosa*	*Pinus sylvestris*	*Pinus strobus*
N	1.64-1.82	2.00	3.60	3.00	3.26
P	0.17-0.19	0.20	0.39	0.23	0.67

of the mineral elements, nitrogen and phosphorus, in kauri seedlings corresponding to maximum growth when compared with values for other conifers (Peterson, 1962). Values are expressed as percentage dry weight.

CONCLUSIONS

Trials of nursery production and planting of kauri have mainly been conducted at Waipoua on a small scale. It has been shown that artificial establishment of this species is feasible, and that it does not present insuperable problems. This is the basis of further experimental work to determine silvicultural regimes, yields, and so on. There is a need now to develop operational procedures for applying these research findings in practice, and work is proceeding with this in view.

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APPENDIX 1

Results of Kauri Seed Storage on Percentage Germination
(From Preest, 1962)

Moisture Content	*4/57*	*8/58*	*7/59*	*6/60*	*5/61*
			Testing Dates		
At —10° C:					
6%	92	62	56	55	59
10%	92	70	64	53	67
15%	92	1	0	1	0
20%	92	0	0	—	—
At 5° C:					
6%	92	78	71	73	81
10%	92	61	41	16	5
15%	92	0	0	—	—
20%	92	0	0	—	—
At 10° C:					
6%	92	81	71	73	82
10%	92	40	3	0	—
15%	92	0	0	—	—
20%	93	0	0	—	—
At 15° C:					
6%	92	78	65	65	52
10%	92	1	0	0	—
15%	92	0	0	—	—
20%	92	0	0	—	—
At room temperature:					
6%	92	81	60	42	36
10%	92	0	0	—	—
15%	92	0	0	—	—
20%	92	0	0	—	—

NOTE: These figures do not include abnormal germinations, and empty seed corrections have not been applied.