Agroforestry in Eastern Otago: results from two long-term experiments

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Abstract

During the first 20 years of a *Pinus radiata* tree rotation, tree growth and pasture yield were assessed under a range of tree spacings at Invermay and Akatore, two coastal sites in Eastern Otago. Pasture yield in association with trees thinned to 100 stems per hectare (sph) was comparable to that from open pasture up to a tree age of 12 years. By the 19th year, however, pasture production declined to 63% of open pasture yield at Invermay and to 42% at Akatore. At 200 and 400 sph at Akatore, pasture yield was similar to that from open pasture at tree age 12 years but declined to 27% and 0% of open pasture yield respectively by year 20.

At both Invermay and Akatore, the ryegrass and clover content of open pasture was relatively constant throughout the term of the trial. However, both the ryegrass and clover content of pasture beneath trees began to decline by tree age 12 years with a very rapid decline at Akatore in the number of pasture species at 200 sph by the 19th year. No pasture remained at 400 sph, after 19 years.

Livestock carrying capacity with sheep on tree treatments at Invermay decreased from 100% of open pasture at year 6 to 60% by year 10. At Akatore, livestock carrying capacity averaged over the 20-year life of the trial was 4.1 stock units per hectare with a maximum of 8.1 stock units at a tree age of 8 years.

Tree growth at both sites was similar, averaging between 1 and 1.1 m/year in height over 20 years, with trees at Invermay at 100 sph averaging 9% greater height and diameter growth than at Akatore. Increasing tree stocking from 100 to 200 to 400 sph at Akatore, resulted in increased tree height, but decreased diameter at breast height. A comparison of the East Otago trees with those in a similar trial at Tikitere (Rotorua) 900 km further north indicated that the southern trees were about 6 years later in their growth pattern by tree age 20 years. On both sites, soil pH tended to be lower in the presence of trees and was significantly lower than in open pasture by year 20.

The results and comparisons with the Tikitere data suggest that, in an integrated agroforestry regime, there will be livestock grazing under the trees further into the tree rotation in Otago than in North Island sites. However, slower tree growth would result in a longer rotation time to harvest. Current recommendations to farmers are to plant trees on the less productive areas of the farm and adopt a tree stocking rate which fully utilises the site.

Keywords: agroforestry, livestock, pasture, *Pinus radiata*, soil pH, tree stocking

Introduction

Forestry is an attractive land use alternative for regional development in Otago and Southland utilising marginal farm land, providing diversification of industry, aiding rural re-population and off-season employment. The potential area of land suitable for forestry in Otago and Southland is 251 000 and 140 000 hectares respectively (Cossens 1977).

Although the potential forestry estate is 391 000 hectares, non-arable hill country carrying less than 8 stock units per hectare in Otago and Southland, totals 582 000 ha. Therefore, the area in forestry could be considerably expanded. Distinct benefits should accrue not only from a large scale forestry operation, but also from small farm woodlots on individual farms, by diversifying income and maintaining enterprise viability. These same issues were discussed over 25 years ago when the agroforestry concept in New Zealand was initially proposed (Knowles *et al.* 1973). At that time, two large-scale agroforestry grazing trials had been established in the North Island at Whatawhata and Rotorua and a further two were set up in Otago under varying initial tree stockings to determine pasture production and livestock carrying capacity under trees and ultimately, tree growth and yield in a 25- to 30-year rotation.

This paper presents an overview of data recorded from 1974 to 1998 for the two Otago trials.

Trial details and methods

The first site at Invermay Agricultural Research Centre, Mosgiel, at an altitude 100 m was planted with *Pinus* *radiata* in 1974 on easy rolling Warepa soils (New Zealand Soil Bureau 1968), which had been sown to pasture in 1952. There were six replicates of three initial tree stocking treatments 0, 400 and 750 stems per ha (sph). The 0.4 ha plots were balanced for north and south aspect with separately fenced replicates grazed by sheep and partially randomised to overcome biased shading of the pasture by trees. Thinning and pruning were carried out in three lifts completed by 1984. The final pruned height was 6 m and the final tree stockings were 0, 80 and 105 sph. For the purposes of this paper, an average tree stocking of 100 sph has been used in the results. Long-term mean January, July and annual air temperatures recorded at Invermay were 14.5, 5.0 and 10.1°C respectively and the mean annual rainfall was 725 mm.

The second site at Akatore was 38 ha in total area and located on moderately steep Kaitangata soils (New Zealand Soil Bureau 1968) of westerly aspect. The existing vegetation of laxly grazed silver tussock (*Poa laevis*) was disced and oversown by air in 1974 with grasses and clovers followed by tree planting over a 2-year period in 1975 and 1976.

Initial tree stocking with *Pinus radiata* for both planting years was 0, 600 and 1200 sph and after final thinning 0, 100, 200 and 400 sph (the initial tree stocking of 600 sph was thinned to either 100 or 200 sph). The final design comprised four replicates of four partially randomised 0.6-ha subplots (trees: 0, 100, 200 400 sph) within each of two perimeter-fenced 4.8-ha main plots stocked separately with either sheep or cattle, the whole being repeated in two blocks (years: 1975, 1976) giving a total of 64 plots. The 1976 block was planted as a mirror image of the 1975, but rotated through 180° along its north-south axis.

Partial randomisation of treatments was used so that open pasture treatments lay on the north and south extremities and the higher stocking tree treatments were towards the middle of each year of planting. Both the 180° rotation and partial randomisation were a manipulation to overcome unrepresentative shading.

The trees planted in 1975 were thinned three times (1981, 1982 and 1984) to final stockings by 1984 and pruned in four lifts to 6 m by 1986. Those trees planted in 1976 had three thinnings (two in 1983 and one in 1984) and pruning to 6 m was completed in 1986.

Fertiliser history

Annual superphosphate topdressing to both sites was usually in August or September as outlined below.

Invermay: At planting in 1974, the 22-year-old pasture had been topdressed with 250 kg/ha/yr of superphosphate and this was continued with few exceptions until 1995. In the 46 years from 1950 to 1995, annual averages of 21 kg P/ha and 31 kg S/ha were applied. Fertiliser was applied by ground machine until 1971 and by aircraft from 1972 to 1995. Lime was applied in 1950 and 1964 at 2 tonnes/ha and molybdenum applied six times at 70 g/ha from 1953 to 1995.

Akatore: Before planting, the site had never been limed or fertilised. Over the period 1976 to 1992 the site was topdressed by aircraft on seven occasions. The average topdressing rate was equivalent to 100 kg/ha/yr of superphosphate. Molybdenum was applied once only at 70 g/ha in 1976.

Grazing management

Invermay: Grazing commenced immediately after planting but was intermittent because of hay making during the initial 3 years. Paddocks were rotationally grazed by sheep to suit pasture growth and except for recorded grazing days from 1974 to 1986, no animal performance records were kept. Pasture length was maintained at about 15cm before stock entered plots and about 2.5 cm at exit.

Akatore: Sheep were not introduced until 6 months after tree planting and cattle not until after 18 months in order to minimise tree damage. Stocking rate was calculated from actual stock grazing days and the area being grazed. The animal stocking rate was adjusted with time so as to give similar grazing pressure on both sheep and cattle paddocks as pasture growth decreased beneath the tree canopy. If seasonal pasture growth was prolific, additional stock were brought in to control the excess feed. Livestock records were averaged to provide annual stocking rates.

Pasture dry matter yield and composition

Invermay: Pasture yield was assessed from 1974 to 1986 by mowing two 5 m^2 cage sites per plot. The Australian difference technique (Lynch 1966) was used from 1974 to 1981 and a rate-of-growth method from 1981 to 1986 (Lynch 1966). No yield data were taken from 1987 to 1989, and herbage mass was measured by electronic pasture probe in 1990/91 and 1992/93 (Crosbie *et al.* 1987).

Akatore: Pasture yield was estimated by the rate-of-growth method from 1980 to 1984 by cutting one 5 m^2 per subplot that is, 16 per replicate. An electronic pasture probe was used to measure herbage mass from 1984 to 1987, however this method became unreliable as pine needle cover increased, so in 1989/90 and 1993/95 the rate-of-growth method was re-introduced with pasture cut by hand from two 0.5 m^2 caged sites per plot.

Table 1 Tree measurements at Invermay and Akatore compared with Tikitere at 14 years (in brackets).

Tree Age (yrs)			3	6	9	11	16	20	(14)
Height (m)	Invermay	100 sph*	1.2	5.4	8.9	10.9	16.2	22.3	-
	Akatore[1]	100sph	1.2	4.9	8.1	10.3	14.4	20.5	20.3
		200 sph	1.2	4.9	8.1	10.7	15.0	22.0	21.4
		400 sph	1.2	4.6	9.7	12.1	16.6	23.7	23.6
DBH (cm)	Invermay	100 sph*	-	11.6	-	23.6	40.2	56.1	-
	Akatore[1]	100 sph	-	7.9	16.4	22.6	33.9	51.1	51.1
		200 sph	-	7.6	16.2	21.3	31.8	45.4	45.1
		400 sph	-	8.7	16.9	22.3	30.9	40.6	38.7

* Mean of (80 + 105) stems per ha treatments at Invermay taken as equivalent to 100 sph.
[1] Means for 1975 and 1976 trees at Akatore.

Pasture composition was assessed at both sites by herbage dissection of the mown yield (Lynch 1966).

Soil chemical analysis

Soils were sampled between May to August annually for the 0–75 mm soil depth at Invermay, and analysed using the MAF Quick Test method (MAF 1984). No attempt was made to stratify samples within or between tree rows.

At Akatore, soil samples were analysed at irregular intervals up to tree age 19 years.

Tree measurements

Damage: At various stages during the trials the trees suffered some damage from stock, wind and earth slumping. Lost trees were replaced 2 years after the initial planting at Invermay and were then protected from stock by electric fencing from 1976 to 1979. Some 25% of trees were affected by sheep browsing in the first 6 years. At Akatore, for the period 1975 to 1980 some 20% of the trees suffered some damage by stock, wind and earth slips. Losses were not severe enough to affect final tree stockings.

Height: Tree heights, and diameters at breast height, were measured annually at Invermay and Akatore, by staff of the New Zealand Forest Research Institute. The tree sample plots comprised 10 trees centrally situated within each plot.

Results and discussion

Tree production

Growth: Tree height increase at both sites averaged a little over 1 m per year by year 20 with that on the 100 sph treatment at Invermay superior to that at Akatore. Both sites had a similar site index (Cossens & Crossan 1995), but the Invermay site had a long history of pastoral farming. There was a height advantage at Akatore as tree stocking increased from 100 to 400 sph, but with a corresponding decrease in stem diameter at breast height. Comparisons of tree measurements with those on a similar trial at Tikitere, near Rotorua, some 900 km north of Akatore, showed Tikitere to be about 6 years ahead of Akatore in growth parameters (Table 1).

Soil chemical analysis

Soil pH, although variable from year to year, was consistent between treatments for each year with a trend from year 16 at both sites for soil pH to be lower in the presence of trees. This decrease in pH was significant at Invermay at 21 years and Akatore at 19 years (Table 2). The changes and trends in soil pH were similar to those observed at Tikitere with the Tikitere trends being generally more marked than at Invermay or Akatore (Hawke & O'Connor 1993).

Soil P and S levels were generally low to adequate in all treatments up to 16 years at both sites, then significantly higher under trees at 19–20 years (data not presented). The levels may have limited pasture production in some years.

Table 2 Soil pH analyses (0–75mm) at Akatore (A) and Invermay (I).

Tree Age (yrs) sph	16 (A)	17 (I)	19 (A)	21 (I)
0	5.2	5.5	5.5	5.5
100	5.2	5.4	5.4	5.3*
200	5.2	-	5.2*	-
400	5.1	-	5.3*	-
SED	0.04	0.05	0.05	0.05

* Significantly different from 0 sph at P<0.05

Pasture yield

Invermay: There was no significant effect of trees on pasture yield as compared with open pasture until after year 12. By years 17 and 19 pasture under trees recorded a highly significant reduction in yield irrespective of tree stocking (Table 3).

Table 3 Annual herbage yield (DM kg/ha) at Invermay and Akatore (mean of 1975 and 1976 plantings).

Tree age (yrs)	1	12	17	19
Invermay				
0 sph	8900	10470	9400	7990
80 sph	9200	10540	5570**	4810**
105 sph	9350	9250	5990**	5330**
SED	1200	520	440	560
Tree Age (yrs)	6	15	19	20
Akatore				
0 sph	7000	7000	5700	4100
100 sph	-	5600*	2400**	1100**
200 sph	6800	5100*	2400**	1100**
400 sph	8100	3600**	460**	0
SED	700	220	530	520

* Significant at P<0.05
** Significant at P<0.01

Table 4 Ryegrass, cocksfoot and clover species composition (%) for Invermay. These data were bulked across the replicates, so means were not subject to statistical analysis.

Tree age (yrs)	sph	1	3	6	9	12	19
Ryegrass	0	30	13	30	43	43	31
	100	26	14	25	9	9	9
Cocksfoot	0	14	36	7	6	4	3
	100	13	34	12	9	9	9
Clover	0	12	3	15	15	16	8
	100	8	4	14	14	9	6

Akatore: Pasture yield was assessed on 10 of the 15 years from 1980 to 1995 and the mean annual yield for open pasture was 6300 kg DM/ha. There were no significant herbage yield differences between the two planting years nor between sheep and cattle treatments, and no differences between tree treatments occurred until after year 12. However, by year 15, trees were having a significant effect on pasture yield and by year 20 the reduction was 73% at 100 and 200 sph and 100% at 400 sph (Table 3) compared with open pasture.

The decline in understorey pasture yields was not as rapid as at Tikitere where at tree age 13 years available pasture was 50, 18 and 0% respectively of that from open pasture at 100, 200 and 400 sph (Hawke 1991). It was only in year 19 that the pasture yield reductions at Invermay and Akatore approached those recorded in year 13 at Tikitere (Cossens & Crossan 1995).

Pasture composition

Invermay: During the first 3 years of the trial, hay was cut on all plots leading to an average decline in ryegrass from 28 to 13.5% but with a marked increase in cocksfoot from 13.5 to 35%. When hay making ceased in year 4, the ryegrass and clover components increased in open pasture up to year 12 with a corresponding decrease in cocksfoot. Under the trees, there was a decline in ryegrass and cocksfoot from year 6, and in clover content from year 9 (Table 4).

Akatore: In year 2, the open pasture was dominantly 56% “other grasses” (browntop, sweet vernal, Yorkshire fog) with ryegrass plus cocksfoot 4% and clovers 6%. At that stage, there was 28% bare ground, a remnant of the land preparation in 1974 before tree planting. The tree treatments tended to have lower ryegrass-cocksfoot and clover composition than open pasture by year 16 and by year 20, there was a marked decline in clovers at 100 and 200 sph, and only traces of all pasture species at 400 sph (Table 5). There was a tendency for sheep pasture to have less clover than cattle pasture, but this was not statistically significant. There was also no significant difference in pasture composition between 1975 and 1976 tree plantings.

Livestock performance

Invermay: Under rotational grazing with sheep, from tree age 1 to 13 years, the mean annual number of grazings for each treatment was 24.0, 20.4 and 18.6 times respectively at 0, 400 and 750 initial sph. The differences were due predominantly to the amount of slash cover from thinning and pruning over this period and not to the direct effect of tree shading on pasture growth.

Table 5 Pasture species composition (%) at Akatore (mean of 1975 and 1976 tree plantings).

Tree age (yrs)	2–3			9–10			16			19/20		
sph	RC	OG	L	RC	OG	L	RC	OG	L	RC	OG	L
0	4	56	6	15	47	10	9	69	6	10	73	8
100	4	56	6	14	60	13	11	72	4	6	69	2
200	4	56	6	10	61	15	6	76	3	9	64	1
400	4	56	6	9	64	11	12	65	3	Tr	Tr	Tr

Notes. 1. RC = Ryegrass and cocksfoot, OG = Other grasses, L = Legumes
2. Balance to 100% made up of weeds, dead matter and pine needles in tree treatments
3. Tr = Traces

Table 6 Animal stocking rates at Akatore (years 1 to 20) (mean of 1975 and 1976 plantings).

Tree age (yrs)	1	3	6	8	10	12	15	16	19	20
su/ha/year	0.3	3.5	5.5	8.1	6.5	6.0	4.2	2.7	3.1	0.9
LCC%	4	43	68	100	84	74	52	33	38	11

LCC = Livestock carrying capacity as a percentage of year 8 where 8.1 su/ha/yr = 100.

Akatore: The mean stocking rates for sheep and cattle over all treatments were 0.3 su/ha/year in year 2, rising to a maximum of 8.1 su/ha/year in year 8, and then declining to 0.9 su/ha/year by year 20 (Table 6) as the tree canopy closed and available pasture decreased. Stocking rate from years 2 to 6 was dictated by the need to prevent possible damage to trees, and later by drought in years 10 and 20. Mean annual stocking rates for both planting years, until tree age 11 years, were sheep 5.1 stock units/ha and cattle 4.6 stock units/ ha. From years 11 to 20, the average stocking rates were sheep 3.6 su/ha and cattle 4.0 su/ha. The average stocking rate over 20 years was sheep 4.2 and cattle 4.1 su/ha/year. The effects of tree stocking on animal stocking rate could not be measured, because replicate plots were not individually fenced.

The potential or theoretical livestock carrying capacity cannot be attained in practice because of the need to avoid animal damage to trees during the tree-establishment and early growth stages.

Conclusions

These long-term trials and the Tikitere trial have shown that wide-spaced agroforestry regimes using *Pinus radiata* result in reductions in pasture production and composition, and livestock performance compared with that from open pasture. Shading effects from the increase in canopy closure is the primary reason for the reductions (Hawke & Knowles 1997). The current recommendations, to achieve a certain minimum level of livestock on the farm and to maintain cash flow, are to vary the proportion of the farm being planted and the rate at which it is planted, rather than just using a low tree-stocking rate (Knowles & Middlemiss 1999). This should result in better utilisation of land in Otago and Southland and more profitable tree crops and pastoral agriculture.

The slower tree-growth rates in Otago will result in longer rotation lengths but greater grazing potential than under similar regimes in the Central North Island.

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