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INTERSPECIFIC COMPETITION BETWEEN *PINUS RADIATA* AND SOME COMMON WEED SPECIES - FIRST YEAR RESULTS

by

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ABSTRACT*

A summary is presented of first year results of a trial designed to quantify the reduction in radiata pine seedling growth caused by competition from a range of important weed species. The experiment was repeated at Rotorua, a moist North Island site, and Rangiora, a South Island site with low summer rainfall. At both sites, radiata pine seedlings were grown on their own and with either herbaceous broadleaves, grass, broom, or gorse; at Rotorua, trees were also grown with buddleia, and pampas. Resource (nutrient and water) levels were varied by factorial +/- irrigation and fertiliser treatments. Rotorua, radiata pine volume after 10 months was greatest in weed-free and gorse plots and least in herbaceous broadleaf, buddleia, and pampas plots. At this time, there was no evidence of competition for water or nutrients. At Rangiora, trees growing with grass and herbaceous broadleaves were substantially reduced in volume compared to the weed free control and the broom and gorse plots. There was essentially no difference in growth on the latter three treatments. Likely mechanisms of competition at the two sites are discussed.

Note: This material is unpublished and must not be cited as a literature reference

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INTRODUCTION

Many studies have demonstrated that radiata pine (*Pinus radiata* D. Don) growth and survival are reduced by the presence of competing plant species (Baker et al., 1988; Balneaves, 1982,1987; Balneaves and Christie, 1988; Balneaves and Henley, 1992; Balneaves and McCord, 1990; Brunsden, 1980; Cellier and Stephens, 1980; Mason,1992; Nambiar and Zed, 1980; Ray et al., 1989; Sands and Nambiar, 1984; Schonau, 1984; Smethurst and Nambiar, 1989; Squire, 1977; Turvey et al., 1983; Turvey and Cameron, 1986; West, 1984). Large growth benefits following removal of competing vegetation are apparent over a wide range of site types and with many different competitor species. Because of this, intensive vegetation management practices ,with heavy emphasis on herbicide use, are typical in the establishment of radiata pine plantations in New Zealand.

This large body of information illustrates the size of short-term crop growth gains following weed control. However, there is relatively little information on the actual mechanisms of the interaction between the crop and associated plants. This understanding is critical for the development of models of crop growth that include weed competition effects and that can be applied to different site types with a range of competitor species. Increased tree growth as a result of competition removal can usually be explained in terms of improved moisture and nutritional conditions or reduced competition for light. These factors enhance physiological processes such as leaf area development, carbon assimilation, diffusive conductance and water-use-efficiency (Boomsma and Hunter, 1990). With the increasing cost of weed control and the pressure against the use of herbicides, it is essential that competition removal operations are applied only to the degree required to give optimal gains, and are targeted against the most damaging species in terms of the impact on crop growth. These objectives can only be achieved by understanding the nature of the interaction between the crop and the competitors, and how this varies over different sites and climates. To this end, a study was designed to investigate the effect on tree growth of some of the prominent New Zealand forest weed species. First-year results are presented from two trials on contrasting site types where treatments included manipulation of site resources (water and nutrients).

METHODS

Sites

Two trial sites were selected, one adjacent to the FRI Rotorua nursery (latitude 38° S, longitude 176° E), and one at Rangiora nursery (latitude 43° S, longitude 172° E). Rotorua has a mean annual rainfall of 1491 mm, a mean annual temperature of 12.7°C, and an annual average raised pan evaporation of 1186 mm (NZMS, 1980). By contrast, Rangiora is much drier with a mean annual rainfall of 702 mm, a mean annual temperature of 11.4°C, and an annual average raised pan evaporation of 1329 mm (based on Christchurch airport data) (NZMS, 1980). There is a deep, moderately fertile pumice soil at Rotorua (yellow-brown Ngakuru loam), which is well drained and has a high moisture holding capacity. The soil at Rangiora nursery consists of a heavy Wakanui silt loam with high nutritional status but low organic content. The site is prone to drought during the period from late spring till late autumn, but during winter and early spring, the soil is often very wet.

Experimental design

At each location, a complete factorial set of treatments was laid out in a split plot design. Treatment factors were weed competition, +/- fertiliser, and +/- irrigation. At Rotorua, there were six weed species (Table 1) plus a weed free control (i.e. a factorial); at Rangiora, there were four weed species (Table 1) plus a control (i.e. a 5x2x2 factorial). The experimental blocks were split into halves, one half being irrigated. Within each irrigated block, fertiliser and competition treatment combinations were completely randomised. At Rangiora there were four replicates installed in 1990. At Rotorua, three replications were installed through time, one per year from 1990-1992. The advantages of replication through time are that effects of different climatic conditions on the competitive interaction can be observed; there is some protection against atypical conditions in the year of installation; and limited manpower and financial resources can be spread over a greater time. The disadvantage is that it takes a long time before the results can be properly analysed based on statistical replication, with the "first year's" growth reported in this study being gathered over a three year period. The trial site at Rangiora and the first two of the replicates at Rotorua were previously under pasture; the third, however, had been clear felled from mature radiata pine during the previous year.

TABLE 1: Species competing with radiata pine at Rotorua and Rangiora

Rotorua	Rangiora
Gorse (*Ulex europaeus* L) Broom (*Cytisus scoparius* L) Buddleia (*Buddleja davidii* Franchet) Pampas (*Cortaderia selloana* (Schult) Asch. et Graeb.) Yorkshire fog (*Holcus lanatus* L) Herbaceous broadleaves (volunteer species)	Gorse Broom Browntop (*Agrostis tenuis* Sibth.) Herbaceous broadleaves (volunteer species)

Installation

To eliminate existing vegetation, predominantly a mixture of herbaceous broadleaves and grasses, the sites were prepared prior to planting using a combination of mechanical cultivation and herbicide applications. GF 17, 1/0 seedlings were lifted from the respective nurseries adjacent to the sites and were planted in July 1990 (also in August 1991 and 1992 at Rotorua) using conventional techniques. To improve stock uniformity, seedlings were graded according to root collar diameter and height to increase uniformity. Tree seedling spacing was 1x1 m, giving 25 trees per plot (5x5 m). At Rotorua, gorse, broom, buddleia, and pampas were planted as seedlings (germinated under glass during the winter of tree planting) at 0.5x0.5 m spacing in the October following tree planting. At the same time as this planting, Yorkshire fog seeds were scattered by hand, and herbaceous broadleaves were allowed to emerge and grow. At Rangiora, broom, gorse, and grass were established by scattering seed onto the plots, the broom and gorse in the autumn prior to planting and the grass the following spring. After planting, herbaceous broadleaves were allowed to emerge and grow in the appropriate plots.

Unwanted weeds were periodically removed from the plots using a combination of hoeing, hand weeding, spot applications of glyphosate, and the use of haloxyfop to remove grasses from the herbaceous broadleaf plots and clopyralid to remove broadleaves from the grass plots.

Irrigation and fertiliser

The goal of irrigation and fertiliser application was to ensure that moisture and nutrients were non-limiting on these respective treatments. At Rotorua, an automatic overhead irrigation system was installed and the trial was irrigated every night with an amount of water greater than the calculated maximum evaporation. In total, this amounted to approximately 1000-1100 mm/yr in excess of annual rainfall. At Rangiora, overhead sprinkler irrigation was limited to once per week during the late-spring and summer months . Although it was realised that this may have been an inadequate moisture supply to achieve the goal of the treatment, it was all that could be achieved with limited resources and manpower. There was no record of the absolute quantity of water applied. To try and achieve a non-limiting nutrient supply, an intensive fertiliser regime was designed. Although the Rotorua site is less fertile than Rangiora, the same regime was applied to each site (Table 2). All fertilisers were broadcast over the plots so that the nutrients were reasonably accessible to both the trees and the weeds.

TABLE 2: Fertiliser regime applied at both Rotorua and Rangiora

Timing	Treatment	Rate (kg/ha)
Pre-plant	15% potassic Magphos (0-8-8-6(S)-20(Ca)-5(Mg))	750
Pre-plant	IBDU (Isobutylidenediurea) (32%N)	500
Pre-plant	FTE 36 (trace elements)	20
At planting	Nitrophoska yellow (15-7-5-4(S)-2.4(Mg))	100
Summer (annually)	Nitrophoska blue (12-5-14-1.2(Mg)+TE)	120
Autumn (annually)	Nitrophoska blue (12-5-14-1.2(Mg)+TE)	120
Spring (year 2 on)	Nitrophoska yellow (15-7-5-4(S)-2.4(Mg))	100

Measurements

Using 9 trees in the centre of each plot, root collar diameter and tree seedling height were measured at the time of planting and repeated at monthly intervals at Rotorua for the first two replications and quarterly with replication three. With tall growing weeds, the height of eight sample plants per plot, and percentage ground cover, were also recorded at regular intervals.

Two, 900 cm^2 samples of vegetation were taken at quarterly intervals from each grass and herbaceous broadleaf plot, and oven-dry weights were recorded. Plant moisture stress (using a pressure bomb), stomatal conductance and photosynthesis (using a LiCor 6200, photosynthesis system) were measured on several days during dry periods in mid-late summer. Physiological measurements were restricted to fertilised plots because of the large number of treatments.

At Rangiora, measurements were limited to crop height and root-collar diameters, weed height and percentage ground cover, taken at the end of the first year.

At Rotorua, a Stephenson screen was installed adjacent to the trial area. Rainfall, temperature (wet and dry bulb) and, incoming solar radiation were continuously recorded. At Rangiora, temperature and humidity were measured using a recording thermohydrograph and maximum and minimum thermometers, and rainfall was measured with a simple rain-gauge.

Data analysis

Tree and weed growth and physiological data were all analysed using ANOVA, after a natural logarithm transformation to stabilise the variance where appropriate, and with initial tree size tested as a covariate in the analysis of crop growth.

RESULTS

ROTORUA TRIAL

Meteorological conditions

Total rainfall at Rotorua for the first 10 months after planting each block was 919, 1074, and 1120 mm for the periods commencing August 1990, 1991, and 1992, respectively. Similarly, average temperatures were 13.7, 12.3, and 12.2°C, respectively. Over the first four months, rainfall was slightly higher and temperatures were cooler with block 3 (499, 562, and 586 mm, and 11.2, 10.5, and 9.9°C for blocks 1, 2, and 3, respectively). Meteorological conditions at Rangiora over the first 10 months were close to average for this area.

Tree growth

Tree seedling volume (calculated as root collar diameter2 x height x pi/4) was significantly influenced by block (P = 0.01), competition treatment (P = 0.0002), and fertiliser application (P < 0.0001) (Figure 1), but there was no effect of irrigation and no significant interactions among any of the experimental factors. Crop volume growth was similar in blocks 1 and 2, but on the third block, planted in 1992, volume was reduced by about 29%. Nevertheless, growth trends over the various treatments were consistent across all blocks. One possible explanation is that nutrient levels were lower in replication 3. This block was atypical in that it had been clear felled from a stand of mature radiata pine in the year prior to establishment of the replication. The possibility that this reduced growth may have resulted from lower fertility will be examined by nutrient analysis of soil samples that were taken prior to establishment of each block. However, given the amount of nutrients added on the fertilised plots and the adequate physical structure across all blocks, it seems unlikely that the growth differences were nutrient related. If the reduced growth on block 3 was not related to water or nutrient supply, it was possibly a result of environmental variables such as temperature. It is possible that small differences over a long period could have significantly influenced growth. This possibility will be examined in subsequent analyses.

Trees in the weed free controls and those growing with gorse had the greatest volume, while those growing with herbaceous broadleaves or buddleia had the smallest volume (36-31% volume reduction, respectively). Although tree volume growth was significantly reduced compared to the control only when in association with herbaceous broadleaves, buddleia, and pampas, the trend clearly indicated growth reductions with all competitors except gorse. Diameter growth trends are the same as for volume, with block, competitor species, and fertiliser application causing significant differences in crop volume. There were small but also statistically significant differences in radiata pine height growth resulting from the block, competition treatment, and fertiliser application (P = 0.0006, P = 0.028, P < 0.0001), respectively) (Figure 2). However, tree volume is a much more sensitive measure of the effect of competition on overall crop growth (Figure 3).

Weed growth

The trends in crop volume growth, averaged over each competition treatment and block, and expressed as a proportion of the control treatment, indicate that crop growth losses commenced earliest with trees growing with herbaceous broadleaves, the most important competitor over the first 10 months. Surprisingly, the Yorkshire fog treatment proved to be a much less effective competitor over the same period. There was a wide variety of species in the herbaceous broadleaf plots, the most prolific being a variety of docks (*Rumex spp.*) but especially sorrel (*Rumex acetosella* L.), plantains (*Plantago spp.*), catsear (*Hypochaeris radicata* L.), willow weed (*Polygonum persicaria* L.), yarrow (*Achillea millefolium* L.), and lotus (*Lotus uliginosis* Schk.) Initial establishment of grasses appeared to be slower, and after 5 months there was an average of 2095 kg/ha above-ground dry matter on the herbaceous broadleaf plots compared to 1303 kg/ha on the slower growing grass treatment. However, growth of both species was considerably enhanced by fertiliser application (2777 kg/ha versus 622 kg/ha). Nine months after planting, there was no significant difference in dry matter production between grasses and herbaceous broadleaves, although the fertiliser effect was still significant (5368 kg/ha with fertiliser versus 4002 kg/ha without).

The fastest growing competitors in terms of height growth were pampas and buddleia. These species began to overtop radiata pine about 7-8 months after crop planting. From this time onwards, crop growth with these treatments was substantially reduced. Broom height growth over this same period was slightly slower than the pampas and buddleia, and individual broom plants did not overtop the pines until about 8-9 months after planting. Broom growth was undoubtedly reduced by infection with the pathogen *Pleiochaeta setosa* (Kirchn.) Hughes, which caused significant mortality in replications 2 and 3. If the broom in all replications had not been sprayed with fungicide (chlorothalonil), it is doubtful whether many plants would have survived. Because of this, the intensity of competition from broom was probably a lot lower than might otherwise have been expected. Weed height growth was increased by fertiliser application but, as with the crop growth, was much reduced on replication 3 compared to replications 1 and 2. Once again, there were no significant interactions.

The negligible effect of gorse on radiata pine growth was almost certainly due to the slow growth of gorse. At the end of the first year, gorse height was still well below that of the radiata pine and percentage ground cover was relatively low. At this same time, all of the other competition treatments has achieved more-or-less complete ground cover.

Mechanisms of competition

Irrigation had no significant effect on tree or weed growth, and there was no significant interaction between irrigation and competition treatment. This implies that water was not a growth-limiting factor on this site, and measurements of plant water stress and stomatal conductance supported this hypothesis. There were no significant differences among treatments in plant moisture stress, stomatal conductance, or photosynthetic rates. Even though measurements were taken during dry periods in mid-late summer, moisture stress was never particularly severe. The average pre-dawn water potential over all treatments and years was -392 kPa, with an average midday to mid-afternoon value of -1216 kPa.

The growth enhancement observed following fertiliser application shows that nutrient supply is limiting growth on this site. The growth benefit from fertiliser application was consistent across all competition treatments (no statistically significant interaction) which implies that interspecific competition for nutrients was probably not an overriding factor during this period. Analysis of foliar nutrient concentrations, when available, will be used to further test this hypothesis. Although the interaction between competition treatment and fertiliser application was not statistically significant, fairly large differences between some treatments were apparent. For example, there was a 44% volume growth increase on weed free fertilised plots compared to unfertilised; at the other extreme there was no volume increase of trees growing with buddleia irrespective of fertiliser application. It is likely that in the latter case, stimulation of buddleia height and leaf area growth following fertiliser application has increased competition for light and negated any benefits from increased nutrient supply. If so, it can be expected that the interaction will become significant over time.

If it is assumed that tree growth was not limited by nutrient supply or water limitations, the most probable mechanism leading to crop growth reduction was competition for light. This was clearly the dominant factor for tall, fast-growing species such as buddleia, pampas, and broom. As soon as these competitors reached approximately the same height as the pine seedlings, crop growth rates began to decline rapidly. It is, however, less certain whether the large growth reduction from the herbaceous broadleaf and, to a lesser extent, the grass treatments, can be explained entirely in terms of competition for light. During the time of peak growth (early summer), these competitors approached and sometimes exceeded the height of the crop. Thus, there was undoubtedly competition for light for a small part of the first year. However, the rapid and severe reduction in crop growth throughout the first year of the herbaceous broadleaf treatment also hints that other mechanisms may have been involved. One possibility is that the development of radiata pine roots was directly inhibited by interactions with roots of the herbaceous broadleaf and possibly grass species.

RANGIORA TRIAL

Tree growth

The contrasting characteristics of the Rangiora site compared to Rotorua nursery resulted in more extreme competitive effects over the first year. Tree volume and height growth 10 months after planting was significantly influenced by the competition treatment ($P < 0.0001$ in both instances) (Figures 4 and 5) but not by the irrigation or fertiliser treatments. There was no significant difference in crop volume for the weed free, broom or gorse plots, but there was a large, and approximately equal, reduction in volume for the grass and herbaceous broadleaf plots. Pine height growth was also reduced by the presence of grass and even more so by herbaceous broadleaves, but these differences were small compared to volume effects. In terms of volume growth, there were significant interactions between competition treatments and both the irrigation and fertiliser treatments. For radiata pine seedlings grown on their own or in association gorse, there was an apparent inhibitory effect from irrigation. Given the low-intensity irrigation regime at this site, it is not known why irrigation should result in growth reductions.

Although there was an apparent growth benefit from fertiliser application for trees growing with gorse, a comparison with the competition-free treatment reveals that this benefit was more a result of the non-fertilised treatment having lower than average growth than a true growth stimulation from the added nutrients.

Weed growth

The estimated percentage ground cover of competing vegetation was used as an index of competition. The grass and herbaceous broadleaf species rapidly attained 100% ground cover. Predominant broadleaves were *Rumex* spp., sorrel, and catsear. The growth of broom and gorse was slower and more patchy, and by April 1991 the average ground cover for both of these species was approximately 40%.

Mechanisms of competition

Because the Rangiora study was not intensively monitored or maintained there is little information on which to base inferences as to likely mechanisms of competition. Surprisingly, there was no significant main effect of irrigation even though summer water limitations are well known in this part of New Zealand (Clinton and Mead, 1990). The most likely explanation is that irrigation once per week during the summer months was insufficient to overcome the moisture limitations. Unfortunately, there were no measurements of moisture stress over the first year to test this hypothesis. The small, but statistically non-significant benefit from irrigation on the grass and herbaceous broadleaf plots hints at a slight growth benefit, possibly from alleviation of moisture stress. The fact that there was no effect of fertiliser and no interaction between competition treatment and fertiliser, suggests that nutrients were non-limiting on this site. This is not a surprising result given the relatively high soil fertility.

As with Rotorua, there was a short period, prior to summer die-back, where the herbaceous species overtopped the radiata pine seedlings. However, the broom plants were only approaching the height of the pines at the end of the first year, and gorse growth was even slower, so that competition for light was not a factor with these two species.

DISCUSSION

At both sites, radiata pine growth reduction was most severely impacted when it was grown in association with herbaceous broadleaves. However, whereas the grass and herbaceous broadleaves were equivalent competitors at Rangiora, the impact of grass on radiata pine growth was much less at Rotorua. Growth trends at Rotorua suggest that when the height of the competitor species is approximately the same as that of the pines, crop growth rates are rapidly reduced. Thus, the fast-growing tall species, namely buddleia and pampas, are having an increasingly severe effect on crop growth. The effect of broom on pine growth at Rotorua is also increasing, but because of the slower broom height growth relative to pampas and buddleia, it is not as severe a competitor over this period. Gorse at Rotorua, and both gorse and broom at Rangiora, grew relatively slowly and, probably because of this, have had a minimal effect on crop growth.

It is known that stem diameter growth of seedling radiata pine is very sensitive to competitor-induced water stress (Nambiar, 1984; Sands and Nambiar, 1984). In areas such as the Central North Island of New Zealand, where there is high, evenly distributed annual rainfall and the pumice soil has a high storage capacity, it might be expected that soil water deficits should not limit radiata pine growth in a typical year (Whitehead and Kelliher, 1991). However, it has been hypothesised that even in this situation, soil water deficits may develop near the soil surface resulting in stress to newly planted radiata pine seedlings with roots restricted to the upper soil layers (Richardson, 1993). Evidence from this trial does not support this hypothesis. Low soil water availability and high leaf-to-air vapour pressure differences during the summer months make water a growth limiting factor to tree growth in the

Canterbury environment. It has been shown that on dry sites in South Australia, even 5-10% weed over can reduce radiata pine growth through water stress (Nambiar and Zed, 1980). Given these results it is perhaps not surprising that low-levels of irrigation had such a moderate effect on crop growth in the climatically similar Canterbury environment.

The development of water stress in pines can vary considerably when they are growing with differing herbaceous species. This is probably a result of variable water usage patterns due to the species' growth habits, physiological characteristics, and type and depth of their rooting systems (Flinn et al., 1979; Jackson et al., 1983; Nambiar and Zed, 1980; Sands and Nambiar, 1984). However, at Rangiora, where competition for water was probably the critical factor, there was no significant difference in crop volume on either the grass or herbaceous broadleaf treatment, although height growth was reduced more by herbaceous broadleaves than grass. By contrast, at Rotorua there was a considerable difference in pine volume growth with the herbaceous broadleaf and grass treatments. The greater effect of the herbaceous broadleaves may be related to their faster rate of establishment. Since there was little evidence to suggest that the herbaceous species reduced radiata pine growth at Rotorua by competing for water or nutrients, the difference between grasses and broadleaves may have been due to the period of competition for light or by direct interference such as the production of allelochemicals (Putnam and Tang, 1986).

It is well known that interspecific competition can limit the ability of the crop to respond to otherwise favourable treatments, such as fertiliser application (Flinn et al., 1979; Flinn and Aeberli, 1982; Squire et al., 1979; Waring, 1972; West, 1984; Woods, 1976). In these trials, the objective was to supply the fertilised plots with excess nutrients so that competition for nutrients was not a factor. It appears that this goal was achieved because although both the trees and weeds responded positively to added nutrients on the less-fertile Rotorua site, there was no interaction between competitor treatment and fertiliser. However, it is anticipated that over the next growing season, such an interaction will become significant as competition for light comes into play. As height growth of the tall, fast growing weed species exceeds radiata pine height, as is occurring with the buddleia, pampas, and broom treatments, radiata pine growth will rapidly slow down.

The mechanism of competition can have important management implications. In general, herbaceous weed control takes the form of a spot or strip treatments centred on the crop tree. If the crop/weed interaction was entirely above-ground, the required spot diameter could be estimated based on the maximum height growth of the herbaceous species relative to tree height. As tree height exceeded the maximum height of the competitors, the spot diameter could be reduced or maintained no longer. However, with root mediated competition for water or nutrients, it is likely that spot diameter would have to be increased over time to give the growing tree free access to water and nutrients. To maximise growth this control would have to be maintained until either the tree roots could reach resources that were unavailable to roots of herbaceous species, possibly deeper in the soil profile, or the crop canopy excluded the herbaceous species through competition for light.

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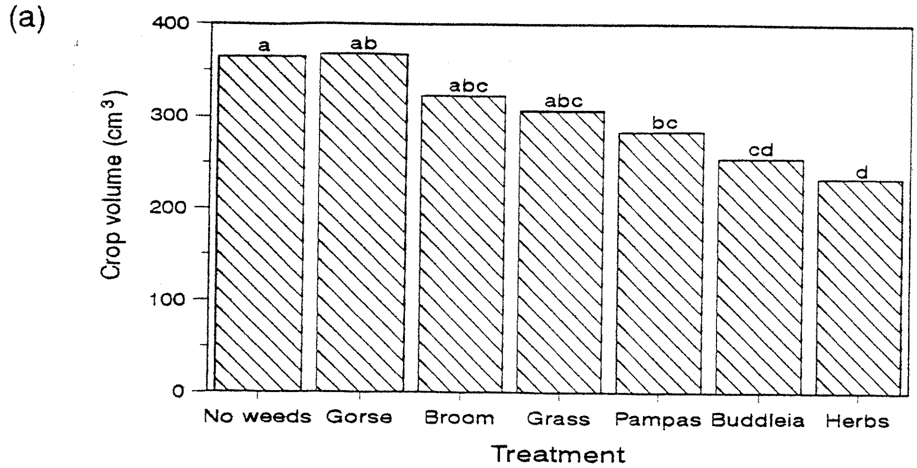

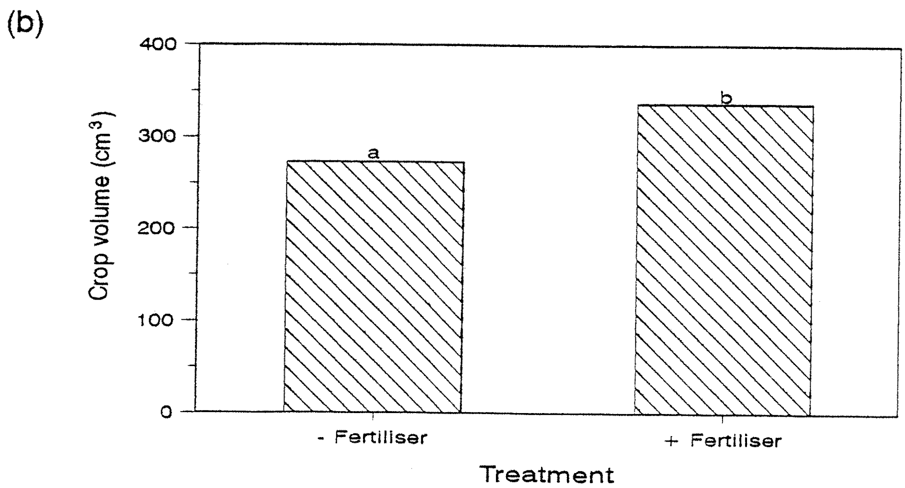

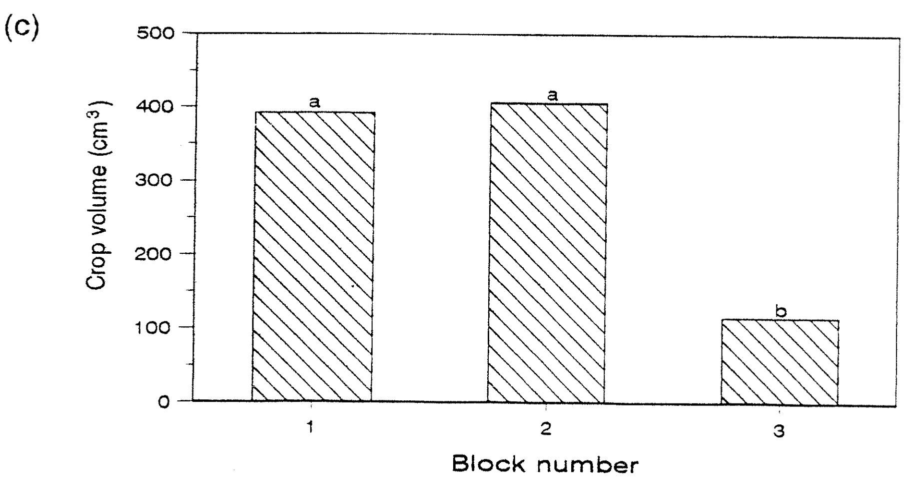

Figure 1: The effect on radiata pine volume of (a) weed competition, (b) fertiliser application, and block number (replicated through time). Bars topped by the same letter are not significantly different at the 5% level according to Fisher's Protected LSD test.

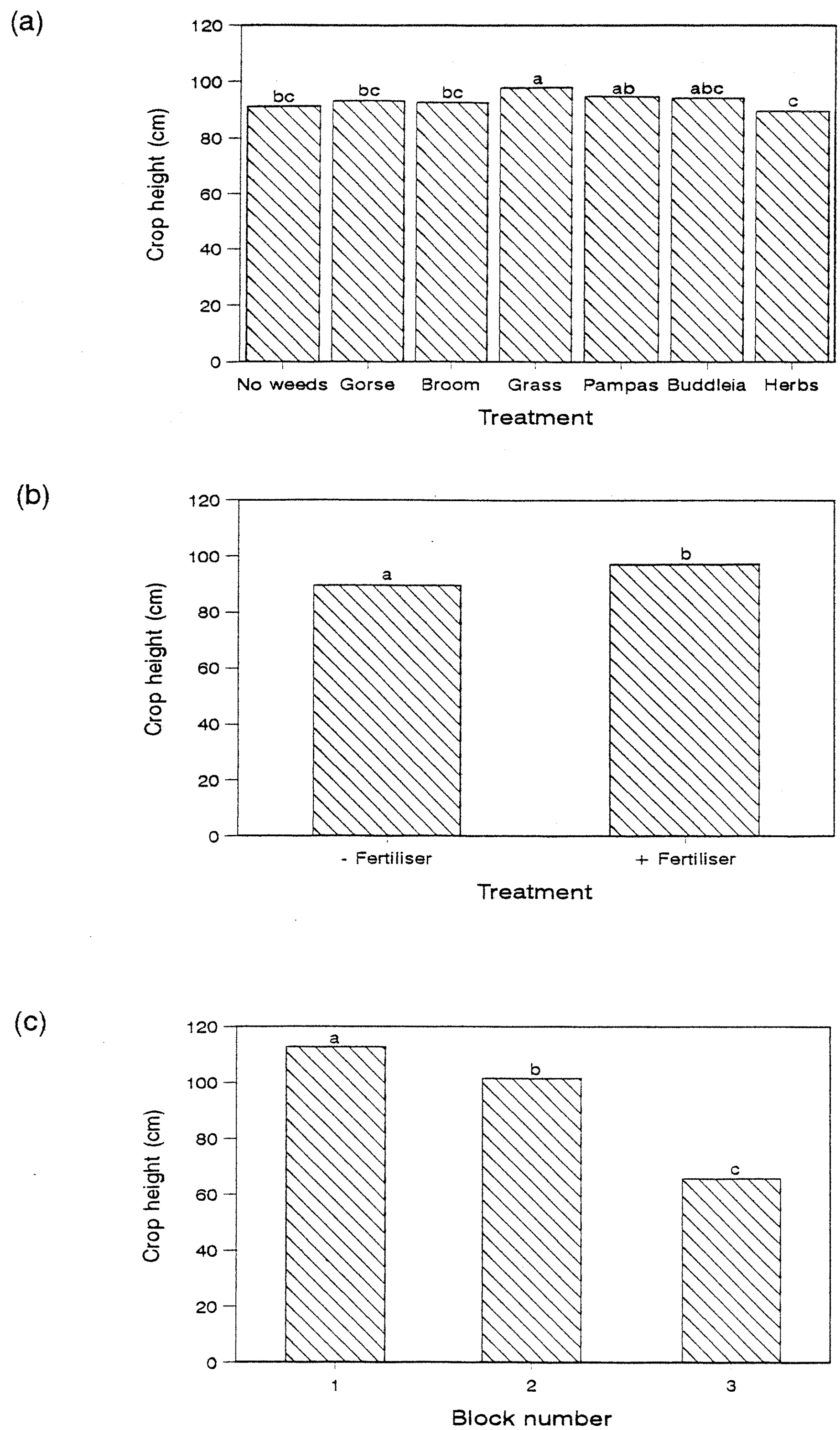

Figure 2: The effect on radiata pine height of (a) weed competition, (b) fertiliser application, and block number (replicated through time). Bars topped by the same letter are not significantly different at the 5% level according to Fisher's Protected LSD test.

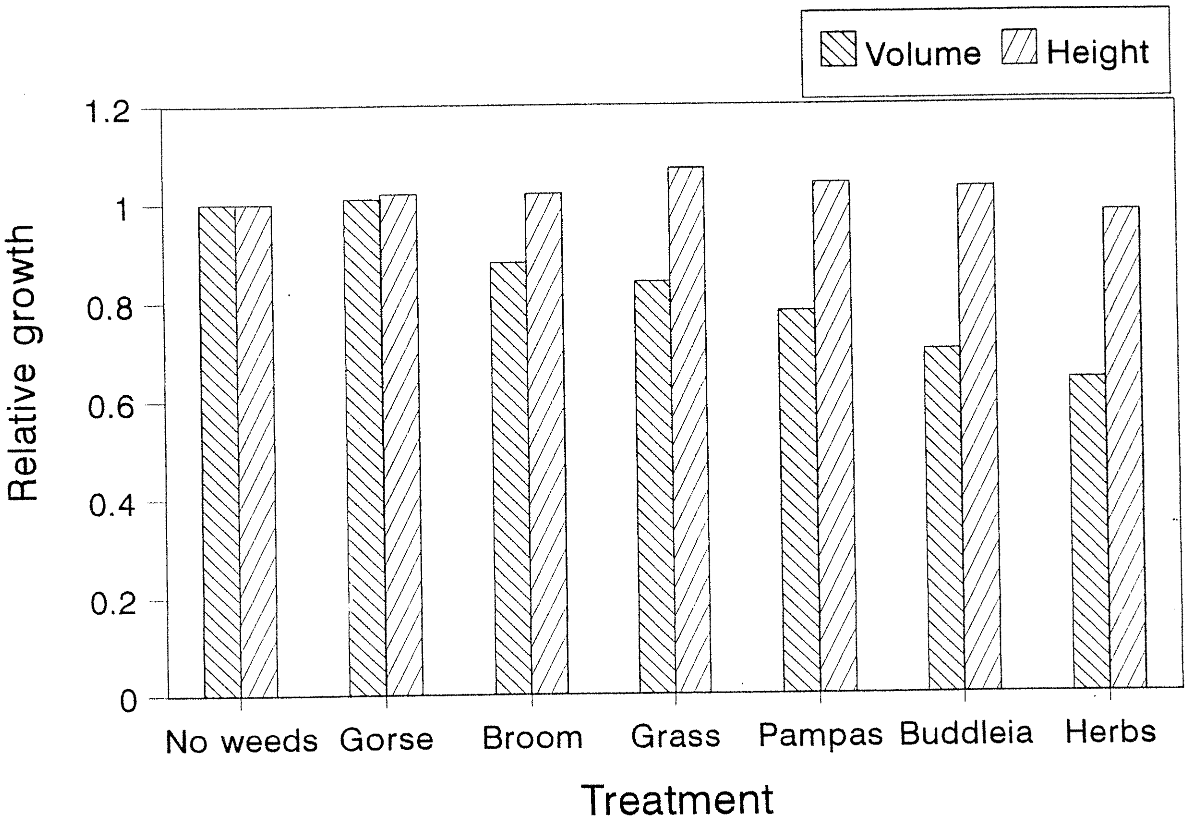

Figure 3: Volume and height growth of radiata pine growing under various competition treatments expressed relative to growth on the weed free controls.

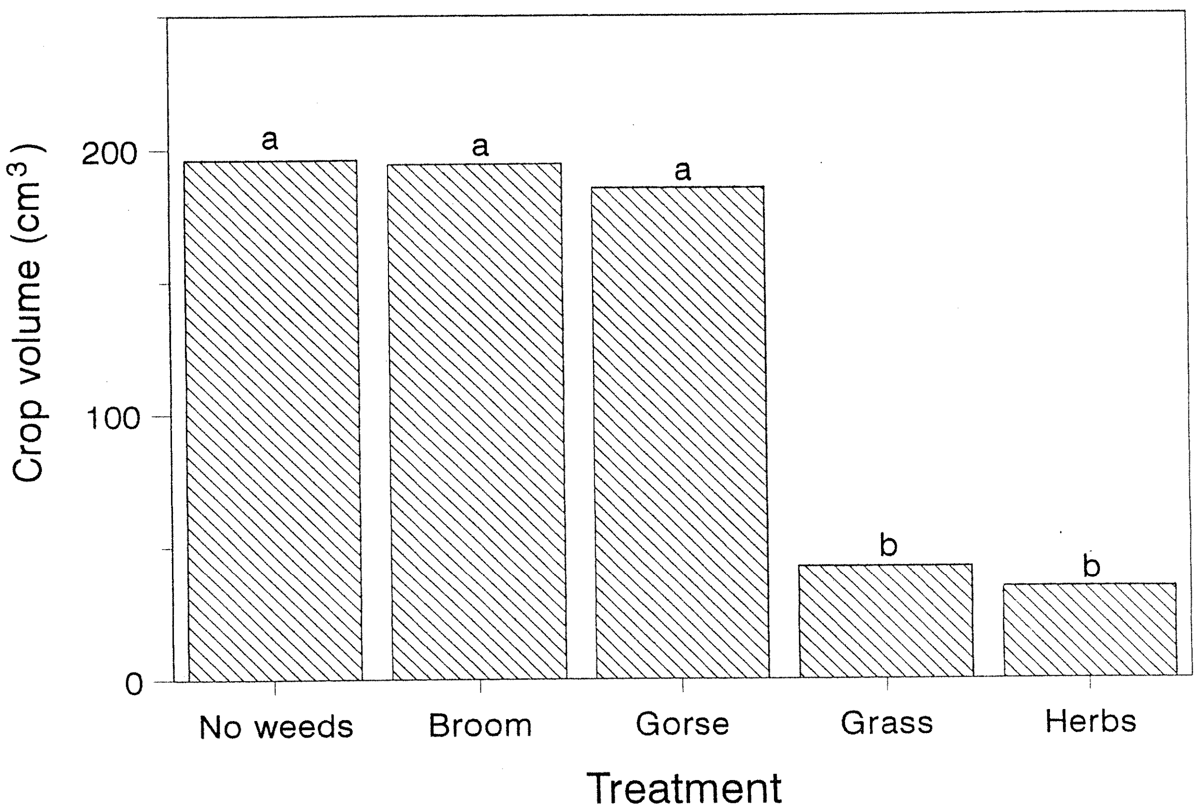

Figure 4: The effect on radiata pine volume of weed competition treatments at Rangiora. Bars topped by the same letter are not significantly different at the 5% level according to Fisher's Protected LSD test.

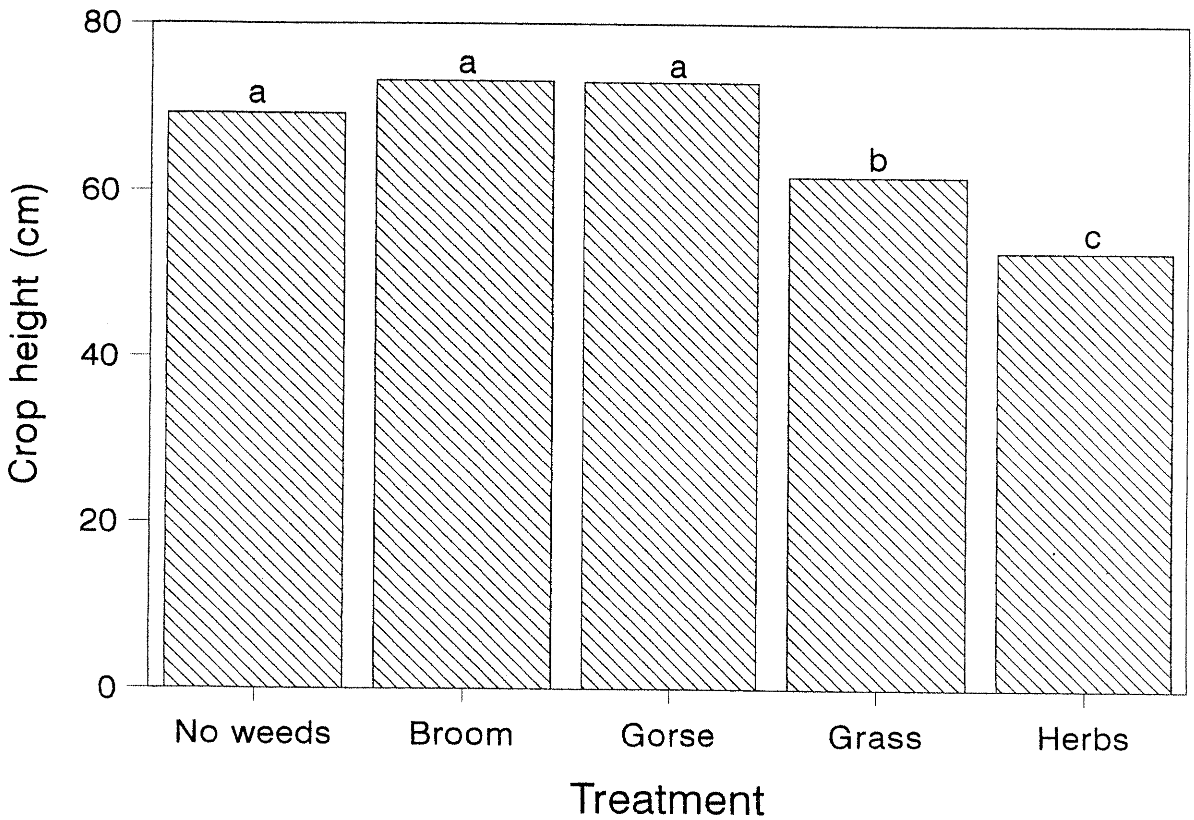

Figure 5: The effect on radiata pine height of weed competition treatments at Rangiora. Bars in a graph with the same letter are not significantly different at the 5% level according to Fisher's Protected LSD test.