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EFFECTS OF HERBACEOUS COMPETITION ON RADIATA PINE GROWTH

by

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EXECUTIVE SUMMARY

The survival and growth rates of radiata pine can be reduced by competition with other species for water, light, and nutrients. A review is presented of the effects of herbaceous competition on radiata pine growth. Likely mechanisms of competition are discussed, and the information is summarised in a form which addresses some of the practical questions relating to management of the crop and the herbaceous competitors. The review identifies several general principles which can be stated with some confidence and indicates some important factors which are not fully understood.

1. Competition from herbaceous species will generally cause large reductions in crop growth.
2. On drier, and possibly less fertile sites, the competition intensity from herbaceous species will be greater than with woody competitors, at least for the first few years after planting.
3. For the greatest growth gains, there must be complete removal of herbaceous species from the crop growth zone; however, this may not be the most cost-effective treatment.
4. There is not enough information to specifically state the optimal duration of competition removal.
5. There is not enough information to specifically state the area around the crop trees which should be maintained competition free (and how this changes over time) for optimal growth benefits.
6. The long-term growth benefit from herbaceous competition control is not known, although likely responses can be hypothesised.
7. On some sites, long-term benefits from herbaceous species may offset early growth losses.
8. It is not generally known how the above responses vary by competitor species, site type, and by climate.

EFFECTS OF HERBACEOUS COMPETITION ON RADIATA PINE GROWTH

INTRODUCTION

Many studies have demonstrated that the survival and growth rates of *Pinus radiata* D. Don crop trees can be reduced by competition with other species for water, light, and nutrients. With the recent upsurge in the practice of oversowing forest sites with mixtures of legumes and grasses, it is becoming more important to understand the process of competition between the crop trees and herbaceous species. For the purposes of this discussion, herbaceous species are defined as annual or perennial grasses or broadleaves without a woody stem. This paper presents a general review of the effects of herbaceous competition on radiata pine growth followed by a more detailed discussion of some of the likely mechanisms of competition. The final section attempts to summarise this information in a form which addresses some of the practical questions relating to management of the crop and the herbaceous competitors.

Clearly, in some situations, control of herbaceous vegetation is essential for reasons other than competition e.g. to modify the environment to reduce the likelihood of out-of-season frost damage. This paper refers only to the process of competition.

Crop growth response to competition

Many studies have demonstrated the effects of competing vegetation on the growth and survival of crop trees in radiata pine plantations in Australia and New Zealand (Baker et al., 1988; Balneaves, 1982; Balneaves and Christie, 1988; Balneaves and McCord, 1990; Brunsden, 1980; Cellier and Stephens, 1980a; Nambiar and Zed, 1980; Ray et al., 1989; Sands and Nambiar, 1984; Smethurst and Nambiar, 1989; Squire, 1977; Squire et al., 1987; Turvey et al., 1983; Turvey and Cameron, 1986; West, 1984). Although most of these studies report large percentage gains in radiata pine volume (or an index of tree volume) with weed control, ranging from approximately 1000% one year after transplanting to about 80% after 10 years, few data relevant to competition from herbaceous species are available beyond the age of 10 years (Richardson, 1992). From these and other studies, it is clear that radiata pine diameter growth is a much more sensitive indicator of competition than height growth.

Crop growth responses to herbaceous weed control have also been noted in established plantations. Release of 4 year old radiata pine from pasture competition increased pine diameter growth over the 12 months of the trial (Clinton and Mead, 1990). other studies have shown similar effects with competition from woody species (J. Balneaves, pers. comm.).

A model has recently been developed to predict the survival and growth of radiata pine up to age 5, in the Bay of Plenty forests (Mason and Whyte, 1992). The model incorporates a range of site preparation treatments (including weed control, cultivation, and fertilisation). The database from which the model was derived included a number of sites where competition from herbaceous species was predominant (although woody species were also present on some sites). The model indicates that in this region, weed control is the single most important treatment in terms of improved tree growth and survival. The effects of weed control on crop growth were greatest at low altitude and there was some evidence of an interaction between weed control and fertiliser application. The inclusion of altitude as a significant variable in the model hints at a relationship between productivity and environmental variables such as temperature, rainfall, and CO_2 concentration which may be correlated with altitude. Also of note, was the improvement in crop uniformity with weed control. However, Mason and Whyte conclude that there is an urgent need to improve the quality of the database describing the effects of competition on crop growth.

Environmental and site effects

The intensity of competition from herbaceous species varies by site and climate. Preliminary results from an experiment in Rotorua, where there is a mean annual rainfall of approximately 1500 mm, demonstrate that in the first 12 months after planting, herbaceous broadleaves have the greatest effect on crop growth out of six types of competitors (herbaceous broadleaves, grass, pampas, broom, buddleia, and gorse) (Figure 1a). At this time, grass was ranked as an intermediate competitor. After 22 months, however, radiata pine growth was lowest in plots containing either broom, pampas, or buddleia. Nevertheless, pine growth in plots with herbaceous broadleaves and grasses was significantly reduced by 38% and 27% respectively, compared to pines in weed free plots (Figure 1b).

A similar trial on a dry South Island site at Rangiora (annual rainfall approximately 750 mm), has provided a graphic example of the severity of competition from both herbaceous broadleaves and grasses over the first 2 years after planting (Figure 2). Intense competition from herbaceous species in dry environments has been noted previously (e.g. Balneaves 1982). Although water is obviously of critical importance in these dry environments, more recent work has also implicated competition for nutrients (Clinton and Mead, 1990; Smethurst and Nambiar, 1989; Woods et al.; 1992).

Given the reduced intensity of competition from herbaceous species on moist sites compared to dry sites, it has been suggested that on high rainfall sites water will not be a limiting resource and grass release may not be necessary (Beveridge and Klomp, 1973; Knowles and Klomp, 1975). However, the research which led to this conclusion was based on measurements of tree height which, as already stated, is a poor indicator of competition. At the Rotorua trial described above, irrigation and fertiliser treatments were also applied with the goal of supplying non-limiting quantities of these resources. Even in this situation there was a significant reduction in tree growth from herbaceous competition.

On high rainfall sites, heavy growth of saturated grass may collapse on seedlings, forming a mat which physically smothers the trees (Balneaves, 1982). This can lead to mortality, stem malformation, and may contribute to toppling.

Duration of competition control

Herbaceous broadleaves and grasses rapidly occupy newly disturbed ground and can vigorously compete with the crop species soon after planting (Ray et al., 1989). However, the period of intense competition may not always be long-lived. Sands and Nambiar (1984) observed that trees became progressively less water-stressed as they aged from 7 months to 3 years after planting, even in the presence of weeds, probably because older trees could gain access to water deep in the soil which was unavailable to the weeds. Thus, the availability of moisture through the soil profile can have an important bearing on the duration of competition and therefore the optimal duration of competition control. The results of Sands and Nambiar may not be generally applicable, however, because of differences in soil type, soil moisture and nutrient levels, rainfall patterns and competitor species.

West (1984) demonstrated that with initial grass release there were large increases in radiata pine growth five years after planting on three sites with mean annual rainfall over the trial period ranging from 884-1470 mm. However, there was no significant benefit from extending the duration of grass release from 1 year to 2 years grass release compared to 1 year. At one site, grass competition was removed for a period of 4 years and fertiliser was applied. This treatment resulted in no significant growth increase compared to a treatment with one years grass control plus fertiliser. Thus, these data suggest that in the Bay of Plenty one year of grass release gives the optimal growth benefit, at least to age 5. One possible problem with this conclusion is that the grass was controlled in 1 m diameter spots around individual trees. It is possible that significant growth benefits may have been obtained had the spot size been increased at age 2 and beyond.

Recent research from the southeast of South Australia has led to the suggestion that on fertile sites where the N supply is high, intense weed control is unnecessary beyond two years after planting (Woods et al., 1992). Conversely, competition for N would remain severe on low-N sites. However, this result on fertile sites is probably dependent on the soil containing water reserves accessible to tree roots after 2 years of weed-free growth.

Weed-free zones

Several studies have observed the effect on crop growth of weed-free zones of varying size (Balneaves, 1987; Balneaves and Henley, in press; Nielsen, 1987). Balneaves and Henley noted that seven years after planting and applying herbicide to radiata pine on a deep loess soil, strip spraying was the most cost-effective treatment (cost/m^3 of wood produced) followed by spots of radius 1.0 m and then spots of 0.75 or 0.5 m (Balneaves and Henley, in press). Broadcast spraying produced the greatest volume gain but was least cost-effective. These conclusions are in contrast to those made 3 years after planting and spraying, when spots of 0.5 m radius were the most cost-effective (Balneaves, 1987). This emphasises the importance of considering long-term growth responses when calculating the cost-benefit of any treatment. In a more complex approach in plantations of hoop pine *(Araucaria cunninghamii* D. Don), an attempt was made to define the dynamic "plant zone", the area around the crop tree which must be weed free to optimise growth, and how this changes over time (Nielsen, 1987). It was concluded that there was no growth advantage in extending the first year plant zone beyond 2.54 m^2 circular area. Height and diameter growth in the fourth and fifth years was significantly increased with a year 1-2 increment in plant zone area. Year 2-3 increment in plant zone area also produced a significant diameter growth response but its importance was considerably less than the year 1-2 increment.

Wagner et al. (1989) noted that crop survival thresholds may differ to growth thresholds. However, there have been no studies designed to make this comparison for species relevant to New Zealand situations.

Competition thresholds

Few studies in New Zealand have been designed specifically to quantify the effects of weed density (or an index of weed density) on crop survival and growth. Fewer still have looked for interactions between weed density and crop density. A large portion of the available information on the growth response of radiata pine to competition comes from herbicide trials where crop growth on herbicide-treated plots is compared to that on untreated controls (Richardson, 1992). Although these studies give an indication of potential growth benefits from removing competition, they give no indication of threshold levels of competition i.e. levels of vegetation abundance where there is a marked increase in the rate of tree survival or growth (Wagner et al., 1989).

In the few studies where crop growth was measured as a function of competitor density, radiata pine growth response conformed to the expected hyperbolic curve (Cousens, 1987) (Figure 3) in the presence of grass (Ray et al., 1989), bracken (Boomsma, 1982; Dutkowski and Boomsma, 1989) or broom (J. Balneaves pers. comm). A curve of this shape indicates that high levels of weed control must be achieved if substantial growth benefits are to be obtained. On dry sites in the south-east of South Australia, complete weed control is usually desired during the establishment phase because even 5-10% weed cover induced water stress severe enough to impair crop growth (Ruiter et al., 1982).

Simple indices of competition have potential for predicting the crop growth response to different levels of competition removal. Using a visual estimate of percentage grass cover one year after planting as an index of competition, 91% of the variation in seedling growth could be accounted for 2 years after planting (Ray et al., 1989).

Long-term growth response

The cost-benefit ratio of any treatment applied to reduce competition levels depends on the treatment cost and long-term growth benefit. As already stated, there are few data available to characterise the long-term growth response of radiata pine to competition removal. Snowdon and Waring (1984) identified two types of growth response to silvicultural treatments. Type 1 responses result from treatments that have little or no permanent effect on soil characteristics and lead to parallel growth trends between treated and untreated stands; Type 2 responses are characterised by a change in productivity (an increase in site carrying capacity) and a divergence of the growth curves of treated and untreated stands (Snowdon and Khanna, 1989) (Figure 4a). Assumptions implicit in these growth responses have been discussed by Mason (1992). Although the positive response to weed control is generally considered as short term, and therefore Type 1 (Snowdon and Khanna, 1989), situations can be conceived where the response is long-term (Type 2). A Type 2 response to vegetation management could be envisaged in situations where a competitor is tolerant to low light conditions and competes throughout the rotation. Although the carrying capacity of the site has not changed *per se*, fewer resources are available to the crop in the untreated stand because competition for water and nutrients persists. This situation is developing at Burnham Forest, in the South Island of New Zealand, where an understorey of broom and grass is still vigorously competing with 13 year old radiata pine (J.Balneaves, pers. comm). A further example can be taken from South Australia. Where it is not controlled, bracken can lead to "spindle", P-deficient stands, which will not close canopy (G. Dutkowski, pers. comm.). This type of situation is most likely to develop in stands with low stocking densities, typical of sawlog regimes in New Zealand. Mid-rotation weed control may be an economically viable option under these circumstances although it is not commonly practised.

A third type of response would conceivably be possible under some conditions. Where herbaceous competitors rapidly occupy a low nutrient site, crop growth relative to stands with weed control is reduced over the first few years by competition for water and nutrients. However, the competitor species also conserves these nutrients which may have otherwise have been lost from the site by leaching. When the competitor is eventually shaded out at crown closure, it will release these nutrients, making them available for accelerated crop growth. Thus, although there may be initial crop growth benefits from competition removal, the growth curve for such stands may eventually fall below that of a stand where there was no initial treatment. This effect has been observed in the sand dune forests in the North of New Zealand (Mead and Gadgil, 1978) and could be termed a Type 3 response (Figure 4b).

Although there are few data describing long-term responses to weed control, these hypotheses are testable and have important implications for cost-effective treatment selection.

Resources in limiting supply

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).

Light

Although there are no quantitative data on inter-specific competition for light in plantations in Australia or New Zealand, several observations can be made. At establishment, seedlings shaded by overtopping vegetation will assimilate less carbon dioxide than unshaded seedlings (Benecke, 1980; Cromer, 1984). The young crop may be overtopped by a wide range of rapidly invading herbaceous or grass species which have high initial growth rates. However, this is usually short-lived because of crop growth and either winter or summer dieback of the herbaceous species because of temperature or moisture limitations, respectively. In the long-term, competition for light is only significant with tall-growing woody species and tall grasses such as pampas.

Of interest in terms of competition for light is the point at which the crop begins to close canopy and light levels available to the competitor are reduced. Thereafter, the intensity of interspecific competition for water and nutrients will also probably decline. The initial crop spacing has an important bearing on the time taken to crown closure, therefore this factor has significant implications for weed/crop competition dynamics. If planting spacing increases, the duration of interspecific competition is likely to increase. Similarly, poor initial crop growth due to poor weed control also increases the time to canopy closure. Timing of thinning can be an important consideration where there is significant competition.

The effect of both crop and weed density on interspecific competition is an area requiring further research, particularly with the low planting densities currently employed in some areas.

Water

It is well established that stem diameter growth of seedling radiata pine is very sensitive to competitor-induced water stress (Nambiar, 1984; Sands and Nambiar, 1984). Annual transpiration and evaporation of intercepted rainfall from radiata pine stands has been estimated at 1000-1500 mm/year (Greenwood et al., 1981; Whitehead and Kelliher, 1991). Thus, in regions 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, soil water deficits should not limit radiata pine growth in a typical year (Whitehead and Kelliher, 1991). However, even in this area, 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. Irregular rainfall distribution and low soil moisture storage can mean that a lack of available moisture can limit growth even in high rainfall areas.

Clearly, where the possibility of water-limited growth losses exist, this will be exacerbated by competing vegetation which can contribute to interception of precipitation and evapotranspiration (Roberts et al., 1982; Whitehead, 1985). Following weed control, improved pine growth rates in areas with low rainfall have often been attributed to increased soil water available to pines (Cellier and Stephens 1980a,b; Nambiar, 1984; Squire 1977; Woods, 1976). During summer in S. Australia, an area with a similar climate to Canterbury, when evaporation exceeds precipitation, midday needle water potentials of radiata pine seedlings growing with weeds are considerably lower than those in weed free plots (Nambiar and Zed, 1980; Nambiar, 1984). As weed cover increased from 0 - 45%, midday needle water potentials during the first summer after transplanting also decreased from -1.0 Mpa to -2.8 MPa, with adverse effects on survival and growth of trees (Nambiar, 1984). On dry sites in South Australia, even 5-10% weed cover can reduce radiata pine growth through water stress (Nambiar and Zed, 1980). Another option to conserve water is mulching, usually with chopped or crushed slash (logging debris) which may have the added benefit of some weed control (Cellier and Stephens 1980b; Flinn et al., 1979a; Squire et al., 1979). Competition for water has also been demonstrated in a dry region of the South Island of

New Zealand. The removal of pasture competition from a 4 year old radiata pine stand increased tree growth primarily because of reduced moisture stress (Clinton and Mead, 1990).

The species of non-crop vegetation can have an important influence on the development of water stress. Different weed species exhibit variable water usage patterns due to their growth habit, physiological characteristics, and type and depth of the rooting system (Flinn et al., 1979b). Variation in weed composition between first and second rotations may help to explain observed differences in tree growth rates (Squire et al., 1979). For example, pines in grass plots were less severely stressed in summer than plots containing sorrel because of grass dieback during summer (Nambiar and Zed, 1980). The relative rooting depth of the crop and its competitors can influence the intensity and duration of competition (Jackson et al., 1983b; Sands and Nambiar,1984). In a comparison of radiata pine with shallow rooting species, competition for water was most pronounced in the first summer after planting, and diminished with each following summer as tree roots tapped water from successively greater depths (Sands and Nambiar, 1984).

Nutrients

Inter-specific competition has been shown to influence the nutrient status of radiata pine. For example, plant competitors reduced the concentrations of foliar nitrogen (N), phosphorus (P), and potassium (K), in radiata pine (Nambiar, 1984).

Weeds may have a particularly important influence on the concentration of soil mineral-N (Smethurst and Nambiar, 1989; Nambiar and Cellier, 1985). Removal of non-crop vegetation from a newly planted site can lead to increased leaching of mineral N (Theodorou and Bowen, 1983). Conversely, the presence of non-crop vegetation can minimise the leaching of N in disturbed forests (Vitousek et al., 1982; McLaughlin et al., 1985).

Interspecific competition can limit the ability of the crop to respond to otherwise favourable treatments. For example, the positive response of radiata pine to N and P fertilisers is often dependent on removal of competitors (Flinn et al., 1979b; Flinn and Aeberli, 1982; Squire et al., 1979; Waring, 1972; West, 1984; Woods, 1976). Addition of fertilisers without vegetation removal can result in increased competitor growth and competition intensity at the expense of tree growth (Flinn et al., 1979b). Low fertiliser efficiency (amount of fertiliser used by the crop species per unit applied) has been attributed, at least in part, to uptake by competing vegetation (Ballard, 1978, 1980; Messina, 1990).

Competition for nutrients is usually difficult to differentiate from competition for water, because water has a large influence on nutrient availability, uptake and crop growth (Nambiar et al., 1984). Well designed experiments are required to partition competition for water and nutrients. Smethurst and Nambiar (1989) investigated the role of weeds (herbaceous broadleaves and grasses) on growth and N nutrition of radiata pine in a region of South Australia with a Mediterranean climate and a podzolised sand soil. The effects of weeds on water stress in pines was eliminated by partial weed control, and nutrients other than N were supplied by fertilisers. Thus, any reduction in tree growth caused by partial, compared to total weed control could be attributed to N supply to pines. Since weeds had little effect on the needle water potential of trees and the annual rates of N-mineralization, but adversely affected N-uptake by trees, and therefore crop growth, it was concluded that the weeds directly competed with trees for N, and thereby aggravated N deficiency in trees. Similar conclusions were obtained by Woods et al. (1992) where N-deficiency and tree growth suppression induced by weeds was overcome by the addition of N-fertiliser.

In a dry region of the South Island of New Zealand, on a moderately fertile loess soil, Clinton and Mead (1990) demonstrated that pasture competed with 4 year old radiata pine for both N and water. However, in this case moisture was considered to be the primary growth-limiting factor.

Associated vegetation, can sometimes provide benefits to the crop which outweigh negative competitive effects. Of particular interest on sites low in N is the use of legumes, as an alternative to mineral sources of N, to improve or maintain the N supply to the newly established crop (Boomsma and Hunter, 1990). In sand dune forests of north-west New Zealand, yellow tree lupin (*Lupinus arboreus* Sims) growing in association with radiata pine, increased available soil N levels and, after 6 years of growth, radiata pine foliar N concentrations (Mead and Gadgil, 1978; Gadgil et al., 1984). The presence of lupins improved radiata volume increment compared to controls for up to 6 years after the lupin died out of the stands (Jackson et al., 1983a). In Australia, annual lupins (*L. angustifolius* L.) grown in association with radiata pine increased stem volume by 16-32% after 4 years (Nambiar and Nethercott, 1987). This response was almost equivalent to repeated additions of fertiliser nitrogen.

In some cases, however, benefits from N-fixing species can be outweighed by their negative effects from competition for water, light, and nutrients, even if soil N increases (Balneaves, 1981; Turvey et al., 1983). In general, it seems likely that benefits will accrue from N-fixing species only where the site is low in N. The positive or negative effects of vegetation growing with the crop must be viewed over a long term. Clover grown with densely planted radiata pine on an infertile podzolic soil was initially a very vigorous competitor, particularly during periods of lower rainfall (Waring and Snowdon, 1985). At the end of 7 years, however, there was no differences in size between trees treated with clover and/or urea but all were larger than trees with no treatment. It appeared that the intense competition by clover for water and nutrients declined when the pines began to dominate the site. N and P released upon the death of the clover then becomes available for pine growth so that, in the longer term, pine growth is stimulated to the same extent as obtained by applying mineral sources of nitrogen. This treatment effect could equate to a Type 3 growth response as discussed previously.

Although non-crop vegetation can reduce the quantity of nutrients apportioned to the crop, total nutrient uptake can be reduced considerably by removal of non-crop vegetation (Smethurst and Nambiar, 1989). Eventually, when trees dominate the growth of the competitors, these accumulated nutrients, could be released back into the soil (Mead and Gadgil, 1978; Waring and Snowdon, 1985). Thus, retention of vegetation at establishment can conserve nutrients and, although there is competition in the short term, benefits may be apparent over time. This concept has been demonstrated on the sand dune forests of northern New Zealand for N-fixing species and for marram grass, a species with a high affinity for N (Mead and Gadgil, 1978). In a radiata pine plantation between two and three years after planting, herbaceous competitors increased the total N uptake and therefore N retention on the site after the application of fertilizer (Woods et al., 1992). The presence of weeds also increased the soil organic matter status and the rate of N mineralisation, and reduced the severity of stem deformation which was enhanced by N fertiliser application in the presence of complete weed control. The advantages of retaining other species on the site led the authors to conclude that strip weed control is probably a better option in many situations than complete weed control.

MANAGEMENT IMPLICATIONS

Site type and climate

Survival and growth of radiata pine are greatly influenced by competition from grasses and herbaceous broadleaves as well as woody competitors. Crop growth reductions as a result of competition have been demonstrated on moist and dry sites, fertile and infertile sites. In a relative sense, competition from herbaceous species is clearly most intense on dry sites and probably also infertile sites. However, in terms of absolute volume reductions growth losses are also important on moist, fertile sites. The large differences over site types and climate in the competition intensity of herbaceous vegetation makes it difficult to apply data from individual experiments in a general sense. One way around this is to take the modelling approach of Mason and Whyte (1992). Unfortunately, as these authors recognised, the current limited database lacks specific information on the type and density of competitors present and the duration of control achieved by the various treatments. These difficulties make it essential for future research to be replicated over a range of site types using a uniform design. The greatest contrasts are likely to be obtained on dry sites versus moist sites. However, more recent research has underlined the importance of competition for nutrients. The incorporation of fertiliser treatments in competition experiments provides a useful means of evaluating the importance of competition for nutrients.

Duration of competition control

The optimal duration of competition control will vary considerably by site and climate. Evidence from moist sites in the Bay of Plenty suggests that one year weed-free is required for most cost-effective growth (West, 1984). However, there may be confounding in this trial because a spot size of 1 m diameter may not be sufficient to eliminate competition after one year. On dry sites, the optimal duration of competition removal is likely to be much greater. Research from South Australia suggests that sites should be maintained competition free for a period of 2 years. However, this result depends on the roots of the seedlings gaining access to an unlimited water supply during this period. After this period (i.e. when water was non-limiting), addition of fertiliser removed competition for N, thus further grass control was unnecessary. These data may be applicable to some sites in New Zealand, but certainly not all. On a site at Rangiora, Clinton and Mead (1990) demonstrated that release of 4 year old radiata pine from herbaceous competition for 12 months resulted in increased diameter growth. Competition for water was thought to be the primary cause although competition for nutrients was also implicated.

To conclude, there is insufficient data to state with confidence the optimum duration of herbaceous competition control on radiata pine sites in New Zealand.

Zone of competition control

There is limited information on this subject from a number of trials. Balneaves (1982) stated that over the first few years after planting growth and survival is generally better with total vegetation control compared to spot applications (1 m^2 spot). However, in a more recent trial which considered costs as well as growth responses, Balneaves and Henley (*in press*) noted that seven years after planting radiata pine, strip spraying was the most cost-effective treatment (cost/m^3 of wood produced) followed by spots of radius 1.0 m and then spots of 0.75 or 0.5 m (Balneaves and Henley, in press). Given the variation in competition intensity over site types and with different competitors (as described above) it is important that this work should be repeated on a variety of site types if a more general result is desirable.

CONCLUSIONS

A review of the effects of herbaceous competition on radiata pine growth reveals several general principles which can be stated with some confidence and identifies some important factors which are not known or fully understood:

1. Competition from herbaceous species will generally cause large reductions in crop growth.

2. On drier, and possibly less fertile sites, the competition intensity from herbaceous species will be greater than with woody competitors, at least for the first few years after planting.

3. For the greatest growth gains, there must be complete removal of herbaceous species from the crop growth zone; however, this may not be the most cost-effective treatment.

4. There is not enough information to specifically state the optimal duration of competition removal.

5. There is not enough information to specifically state the area around the crop trees which should be maintained competition free (and how this changes over time) for optimal growth benefits.

6. The long-term growth benefit from herbaceous competition control is not known, although likely responses can be hypothesised.

7. On some sites, benefits from herbaceous species may offset early growth losses.

8. It is not generally known how the above responses vary by competitor species, site type, and by climate.

Current research projects and proposals to the Site Management Cooperative have objectives which will ultimately provide answers to the above questions. Existing trials at Eyrewell and Rotorua are studying mechanisms of competition for a range of competitors on contrasting sites. Furthermore, water and nutrient resources are being manipulated to examine the effects of these resources on crop growth and site productivity. As well as providing much needed basic information on competition from some of our important competitors, these studies will help to generate more general models of competition which account for competitor species, site types, and climate. An understanding of the processes of competition will help with the prediction of likely long-term crop responses to competition removal.

The Competition Database is designed to store existing and future data from any study which includes competition control in the design. In addition, specific trials will be designed and installed to measure the long-term growth benefit from competition control over a range of site types. Data from the database will be passed onto modelers to develop models of competition.

Current proposals to the Cooperative have the objective of defining more clearly the optimal duration of weed control and the desirable area of competition removal around individual trees. These trials will be designed to be maintained over a rotation so that they will also contribute to the Competition Database.

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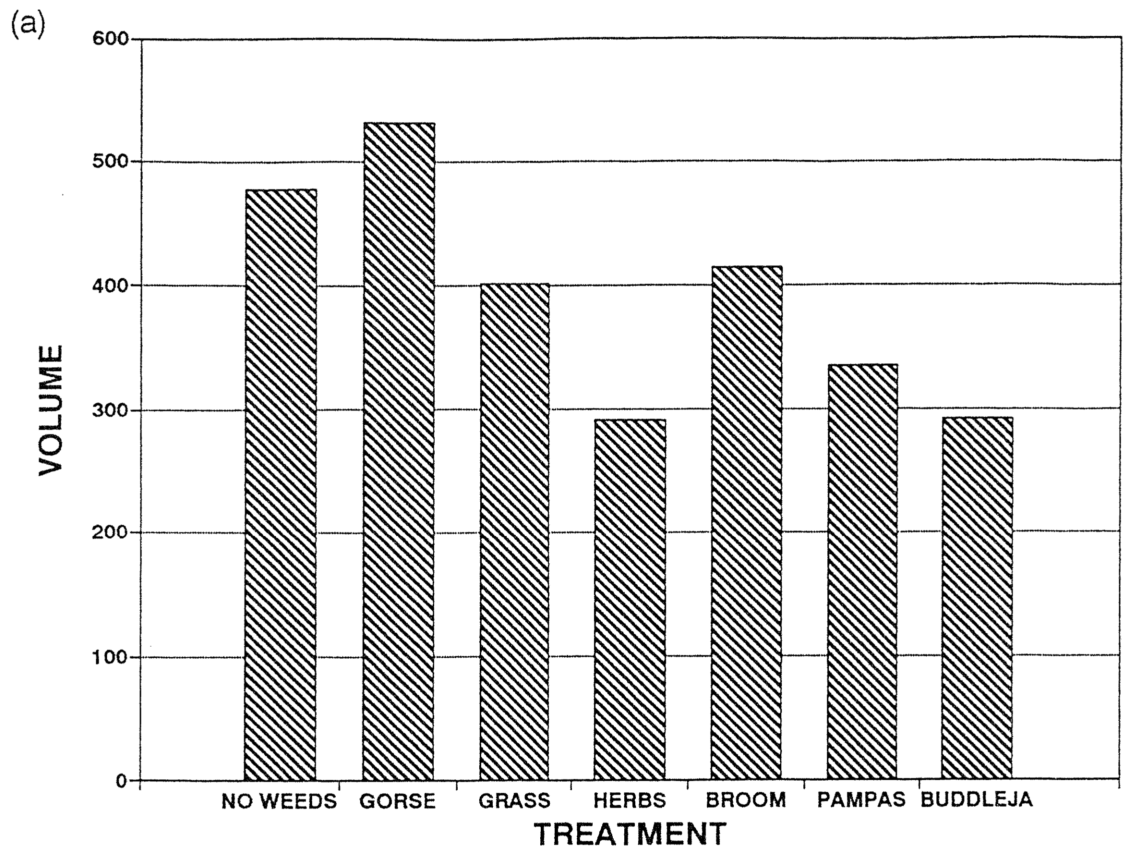

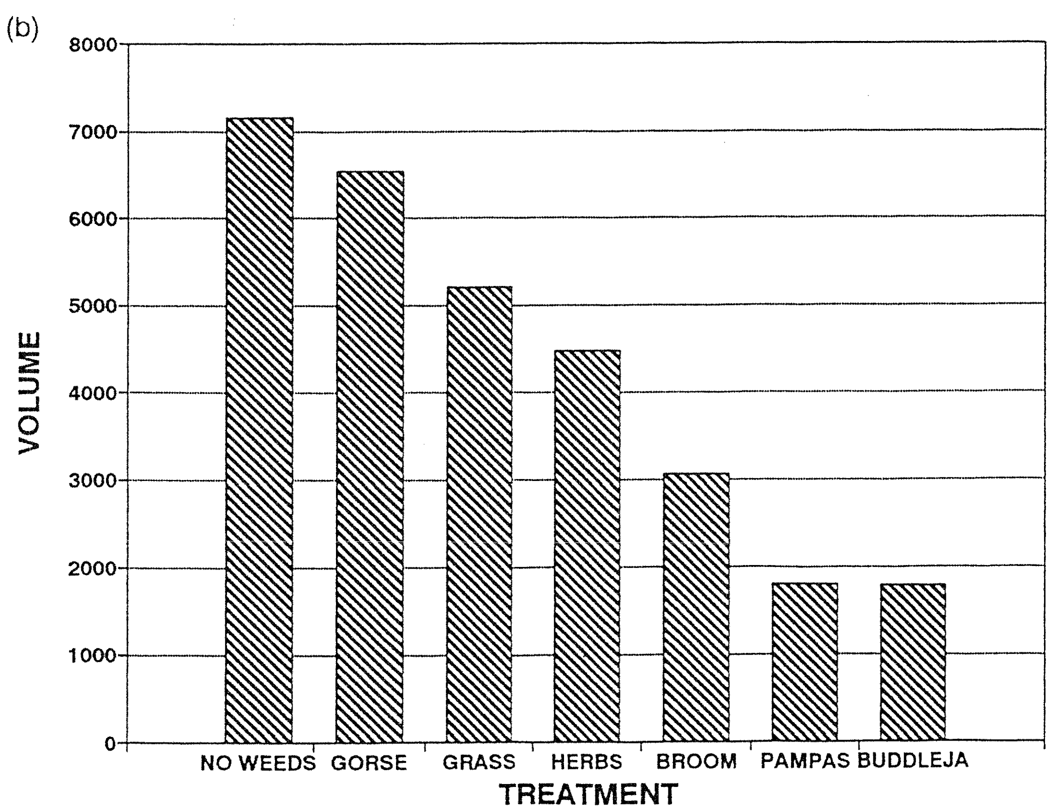

Figure 1: Effect of plant competition on radiata pine volume (a) 10 months and (b) 22 months after planting on a moist site.

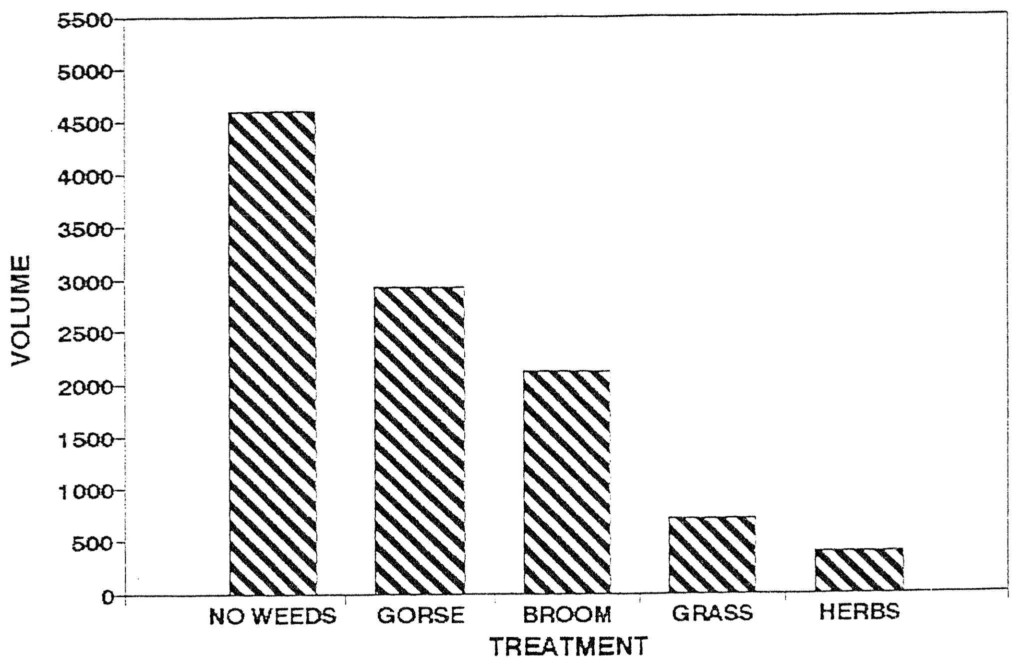

Figure 2: Effect of plant competition on radiata pine volume 22 months after planting on a dry site.

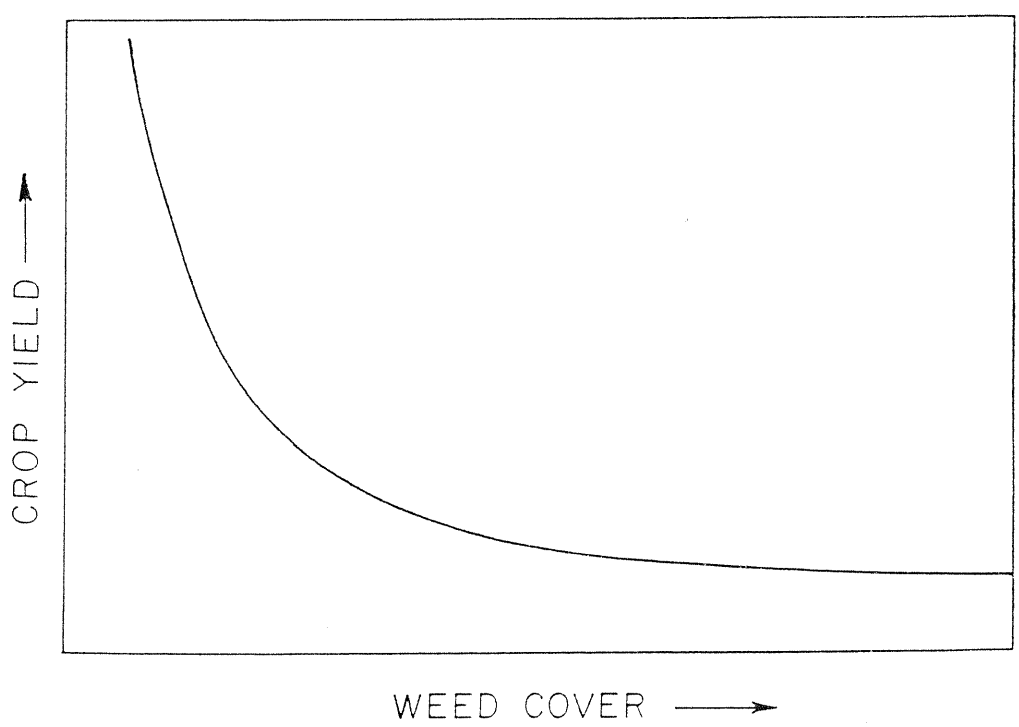

Figure 3: Effect of increasing weed density on crop yield: .

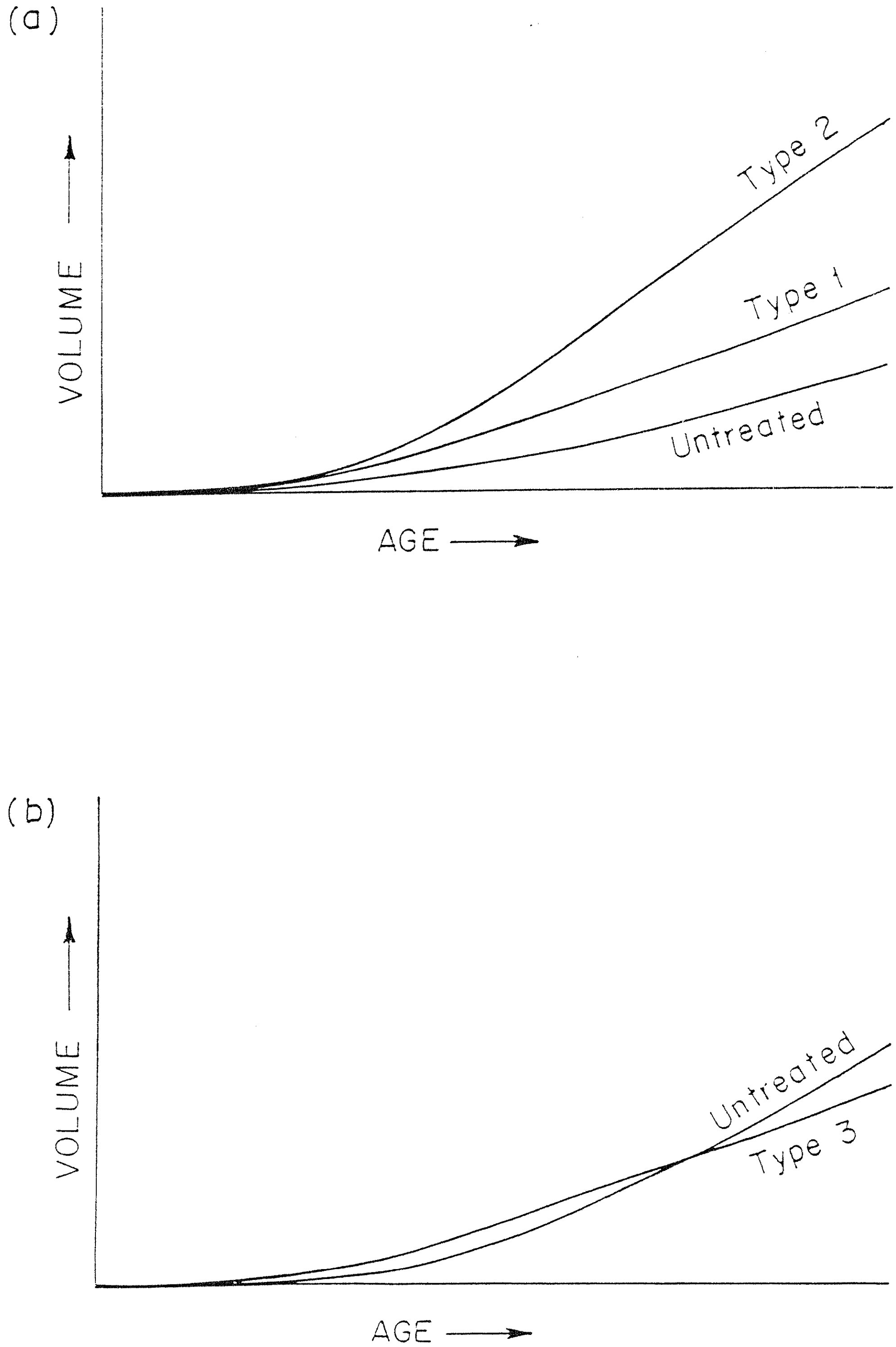

Figure 4: Possible radiata pine growth responses to interspecific competition on (a) fertile and (b) infertile sites.