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OPTIMISING SPOT WEED CONTROL

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ABSTRACT

Spot spraying, where only the area around individual trees is treated, is becoming an increasingly important method of herbicide application during establishment of radiata pine (*Pinus radiata* D. Don) plantations in New Zealand. Minimising the spot size is advantageous in terms of reducing costs and has perceived environmental benefits from reduced herbicide use. Trials were undertaken at two sites to determine the effect of area and duration of spot weed control on radiata pine growth. One year after planting, crop growth benefits from weed control, were proportionally greater on the most productive site. At this site, crop height and diameter growth continued to increase, albeit at a declining rate, as spot size was increased to the point of complete weed control. However, on the less productive site, significant growth benefits were only apparent from the smallest spot size treatment. At both sites, diameter growth was more sensitive to weed control than height growth.

Keywords: weed control; competition; spot spraying; herbicide; *Pinus radiata*.

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 plant species for water, light, and nutrients (Richardson, 1993a.b). Consequently, weed control is normally undertaken during the period of crop establishment. Although herbicide application is the standard method of weed control, these chemicals are expensive and there is public pressure against their use. Hence, it is important to use the minimum quantity of herbicide to greatest effect. Spot applications, where only the ground area around individual trees is treated, are becoming increasingly popular, partly because of the reduction in the quantity of herbicides used. For example, with a 1.5 m diameter spot and 833 stems per hectare, only about 15% of the area is treated with herbicide compared with broadcast treatment; this provides large cost reductions and perceived environmental benefits. Spot spraying is most appropriate on sites covered predominantly with herbaceous vegetation (defined as annual or perennial grasses or broadleaves without a woody stem). A significant proportion of cutover sites can be placed in this category because of the practice of oversowing with mixtures of legumes and grasses, and with a high proportion of new plantings on fertile pasture sites.

Two important management issues related to spot spraying are the definition of (1) the optimal spot size and (2) the duration of weed control. These two factors dictate the proportion of a site that has to be treated and how many times the application has to be repeated, therefore defining the amount of herbicide required. To select the ideal spot diameter and duration of weed control, the cost of treatment must be balanced against the benefits in terms of growth, survival, and quality of the crop. Although some of these factors have received limited study, there has been no conclusive definition of the optimum area and duration of herbaceous weed control on radiata pine growth and survival in New Zealand (Balneaves, 1987; Balneaves and Henley 1992; Clinton and Mead, 1990; West, 1984). However, it is clear that these parameters will vary with soil type, climate, and competitor species (Richardson, 1993b). It has been suggested that on moist sites in the Bay of Plenty, one year weed-free is required for most cost-effective growth (West, 1984). However, this conclusion may not be valid because the maximum spot size used in these experiments was 1 m diameter; this may not be sufficient to eliminate competition and maximise growth even within the first year after planting. 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 (Sands and Nambiar, 1984). However, this result appears to depend on the roots of the seedlings gaining access to an unlimited water supply during this period. 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.

This paper presents first year growth data from two trials designed to define the optimal area and duration of weed control. Both sites were located in the central North Island region of New Zealand.

METHODS

Site location and history

Trials were undertaken in Kaingaroa and Kinleith Forests. Both sites have light pumice soils, elevations of 460 and 584 m above sea level, and mean annual rainfalls of 1483 and 1585 mm for Kaingaroa and Kinleith, respectively.

Kaingaroa

The trial was located in Compartment 1135 (next to Northern Boundary Road). This compartment was first planted with radiata pine in 1965 and was clear felled in November 1989. Following harvesting, the site was V-bladed, replanted with radiata pine and was both aerially and spot released using herbicides. By 1993, however, the decision was made to replant because of severe competition from broom and bracken. The site was desiccated with an aerial application of glyphosate (5.4 kg a.e./ha) in February 1993, followed by roller-crushing in March 1993. Finally, the site was oversown with a mixture of 10 kg/ha Yorkshire fog (*Holcus lanatus* L.) plus 5 kg/ha lotus (*Lotus uliginosus* Schk.) in April 1993. In August, pine seedlings were planted on top of the V-blade mounds at a spacing of approximately 3 m within rows and 3-4 m between rows (depending on location of mounds). In September 1993 spot treatments were applied using a mixture of terbuthylazine (7.5 kg a.i./ha), haloxyfop (0.5 kg a.e./ha) and clopyralid (0.6 kg a.i./ha).

Kinleith

The trial was located adjacent to Pelican Road on a site from which radiata pine had been harvested in 1992. In January 1993 the site was sprayed using a mixture of glyphosate (3.2 kg a.e./ha), metsulfuron methyl (0.1 kg a.i./ha), Silwet L-77, an organosilicone surfactant (0.3 l/ha), and Delfoam (Yates NZ Ltd), a foaming agent (0.35 l/ha). After planting at a 6 x 6 m spacing in winter 1993, the site was oversown in October using a mixture of 10 kg/ha annual ryegrass (*Lolium multiflorum* L.), 3 kg/ha lotus (*L. uliginosus*), 1.5 kg/ha browntop *(Agrostis capillaris* L.), and 1.5 kg/ha cocksfoot (*Dactylis glomerata* L.). In December 1993 spot treatments were applied using a mixture of haloxyfop (0.5 kg a.e./ha), clopyralid (0.6 kg a.i./ha), and simazine (10 kg a.i./ha).

Experimental design

At Kaingaroa both a "short-term" and a "long-term" experiment were installed. The short-term experiment contained a large number of treatments and was designed to last for about 7 years, whereas the long-term experiment incorporated fewer treatments but was designed to last for a complete rotation. The short-term experiment examined effects of weed control and broadcast fertiliser application. Fourteen levels of weed control (combinations of area treated and duration) (Table 1) and two levels of fertiliser, i.e. plus or minus fertiliser application, were applied. Each treatment was replicated 20 times in a randomised block design; fertiliser was applied as a split block treatment and weed control to individual tree plots within each split-block. Each weed control treatment was randomly allocated to four trees within each split-block.

The long-term experiment at Kaingaroa consisted of five treatments, listed below, replicated five times in a randomised block design:

1. Untreated (no weed control).
2. Complete weed control (throughout the rotation).
3. Two year weed control with a 2 m diameter spot.
4. Two year weed control with a 1 m diameter spot.
5. Complete weed control (throughout the rotation) plus excess nutrient supply.

Plot size was 45 m x 45 m with a 10 m buffer giving an inner plot of 25 x 25 m. With an initial planting spacing of 3 x 4 m, this will give approximately 18-19 trees/plot at 300 stems/ha final stocking.

At Kinleith the basic design was the same except there was no fertiliser treatment, two extra weed control treatments were included (Table 1), and there were 30 blocks. The actual area treated in the "complete" weed control treatments also varied between Kinleith and Kaingaroa because of planting spacing differences.

Fertiliser application

A fertiliser regime was designed for the Kaingaroa trial to ensure that tree growth was not limited by insufficient nutrient supply (Dr. M. Skinner, NZFRI, *pers. comm.*). The following elements were applied in the Spring following planting.

- nitrogen at 50 kg N/ha as urea;
- phosphorus at 50 kg P/ha as long-life super;
- magnesium at 100 kg Mg/ha as calcined magnesite;
- boron at 6 kg B/ha as ulexite.

Weed control

Weed control treatments were applied using forestry spraying contractors with modified drench guns and standard cone nozzles. Spot size was varied by changing the height of application. Complete weed control was achieved using either knapsacks and fan nozzles, or a small boom sprayer with fan nozzles.

Measurements

The heights and diameters of all trees were measured and their health was assessed shortly after planting and again at the end of the first year (i.e. the winter following planting). Six months after spraying, actual spot size was measured along the longest axis of the spot and at 90° to this. A mean diameter was calculated from these two measurements. Percentage weed ground cover within a 1 m diameter of each tree was estimated and the distance was measured from the centre of the spot to each tree. The above-ground biomass of herbaceous vegetation on untreated areas was measured during summer by harvesting all vegetation in up to twenty randomly located quadrats (0.3 x 0.3 m^2 at Kaingaroa and 0.5 x 0.5 m^2 at Kinleith).

Analysis

The effect of spot size on tree survival and growth was assessed using analysis of variance. Initial tree diameter, percentage weed ground cover, and tree position within the spot were all tested as possible covariates. At Kaingaroa, a few trees were planted between the V-blade mounds on areas devoid of topsoil; where this occurred the trees were omitted from the analysis.

All individual tree data from the short term experiments and plot means from the long term experiment were fitted to the general non -linear model :

$dia2 = (a + b.dia1)(1 + c.exp^{d.spdia})$ where,

a, b, c, and d are regression coefficients dia1 is the measured tree diameter at the time of planting

dia2 is the predicted tree diameter 1 year after planting,

spdia is the mean spot diameter.

An equivalent model was used to examine effects on height growth. To test the hypothesis that the relative effect of weed control on crop growth is greatest when the initial diameter is small, an additional term was added to the model to account for interactive effects of initial diameter:
$dia2 = (a + b.dia1)(1 + (c1 + c2.dia1)exp^{d.spdia})$.

Non-linear regression analysis was undertaken using the Gauss-Newton method in the SAS statistical package.

RESULTS

Spot size

The accuracy of the spot applications is described in terms of comparisons of requested and measured spot diameters (Table 2). Although there should in theory be no spot sizes recorded for the no weed control treatments, Table 2 shows that this is not the case. The reasons for this discrepancy are: (1) there were a few application errors; and (2) in some areas there was no growth of non-crop vegetation even though there was no weed control. Overall, Table 2 shows that there were substantial discrepancies between requested and mean measured spot diameters in all of the experiments. The major source of this error was likely to be variability in the height of the spot gun nozzle. The applications were made by experienced contractors who knew that their performace was to be carefully measured and suggests that there may be room for improvement in application methods. Alternatively, however, with only a single spot size to be applied operationally, results may in fact be more consistent.

As a result of the differences between requested and actual spot diameters, analysis of variance was performed on four groups of trees with spot diameters classified according to the ranges of 0, 0-1.5, 1.5-2.5, and >2.5 m.

A second consideration in terms of application accuracy is the position of the tree within the spot. In general the performance in this respect was satisfactory with, on average, the tree being less than 20% of the radius from the centre of the spot for almost all treatments. This factor was not significant ($P > 0.05$) as a covariate in analyses of variance with tree height and diameter as dependent variables.

Growth and survival

There were only very small growth differences between results from the Kaingaroa long- and short-term experiments, therefore in the following sections only results from the short-term trial have been presented in detail.

At both sites, there were significant differences in tree height and diameter resulting from weed control treatments ($P = 0.0001$ for both variables at Kaingaroa and Kinleith). At Kaingaroa, diameter growth gains of between 75 and 99% (long- and short-term experiments, respectively) were observed comparing the no weed control and complete weed control treatments (Figure 1). With each increase in spot diameter class there was an associated significant increase in tree diameter. There was no significant effect on growth from fertiliser application ($P > 0.11$ for both diameter and height). Absolute tree diameter growth and differences among treatments were much smaller at Kinleith, with only a 17% increase between the same treatments (Figure 1). This is despite that mean initial tree size at planting was greater at Kinleith (6 mm versus 4 mm root collar diameter at Kaingaroa).

At both sites, effects of spot weed control on height growth were less marked (Figure 2). At Kaingaroa there was 34% growth increase comparing the maximum and minimum spot size classes, but at Kinleith there was no significant effects of spot size on height growth. Height growth is known to be a poor indicator of competition (Richardson et al., 1994?)

At Kaingaroa, mortality at the end of the first year after planting approached 10% with no significant differences among spot size treatments (P= 0.32) (Figure 3). At Kinleith, mortality was generally low except for the no weed control treatment where it was approximately 8% and significantly higher than the other treatments (P = 0.002). Although in most cases the cause of mortality could not be conclusively identified, there was a high incidence of browsing damage from rabbits in isolated parts of the Kaingaroa trial (although average values for the whole trial were fairly low) (Figure 4). There was also a positive correlation between degree of weed control and browsing damage, with significantly more trees damaged in the complete weed control treatment. Prior to undertaking this trial it was expected that mortality would be greatest in the no weed control treatment. The increase in browsing damage with degree of weed control may help to explain why this was not observed on this site.

Growth trends

Height and diameter growth trends were investigated using non-linear regression analysis. The only significant independent variables were initial tree size and spot size; there was no further benefit from adding to the model information on spot application accuracy and percentage weed cover within the spot. At Kaingaroa there was a strong trend for increased tree growth with increased spot size up to the point of complete weed control (Figure 5a,b). However, with the rate of increase in growth rate declining as spot size is increased, there will be diminishing returns for each increase in spot size. At Kinleith, diameter growth gains from extending weed control beyond a 1 m diameter spot were marginal. Similar trends were observed for height growth responses.

There was no evidence to indicate there was a significant interaction between diameter growth and intitial tree size. In other words, the relative benefit from weed control was the same whatever the initial tree size. However, the range of initial seedling size used in each experiment was fairly small, so the the possibility cannot be excluded that an interaction may exist if greater extremes in size were tested.

Table 3 shows the amount of variation in radiata pine height and diameter growth explained by the regression models for each experiement. In the short term trials (both Kaingaroa and Kinleith), where the model was based on individual tree growth data, between 35 and 27% of all variation in diameter growth and 25 - 43% of the variation in height growth was accounted for. As expected, the percentage variation explained by the model with the long-term trial model was much greater because each data point was a mean of approximately 40-50 trees. Nevertheless, 93 percent of the variation explained by the model is very high and demonstrates that micro-environmental, fertility, and other factors were not causing large differences in tree growth across the site.

Weed growth

Herbaceous weed biomass on unsprayed areas was over twice as high at Kaingaroa than at Kinleith (means of 6,890 and 3,015 kg/ha and standard errors of 865 and 294 kg/ha, respectively). Observations on ground cover also indicated much greater weed growth at Kaingaroa.

DISCUSSION

Absolute tree growth and herbaceous weed biomass over the first year after planting was much greater at Kaingaroa than Kinleith. Mean annual rainfall at each site was similar, so the most likely factors causing the productivity differences were temperature and soil fertility. The Kaingaroa site was fertile enough that there was no growth response to a complete fertiliser application in combination with total weed control. Unfortunately there was no fertiliser treatment at Kinleith. The 120 m lower elevation at Kaingaroa would likely result in milder temperatures that could also have contributed to the greater overall growth. Mason and Whyte (1992) have shown the importance of altitude in predicting radiata pine growth up to age 5 in the central North Island.

The response to weed control was also much greater at Kaingaroa than Kinleith, possibly because the more vigorous growth of non-crop vegetation caused increased interspecific plant competition at Kaingaroa. At Kinleith, factors other than competition are probably limiting tree growth so weed control is not so critical. However, when weed competition is added to these other environmental stresses a significant increase in mortality was observed. Mason and Whyte (1992) demonstrated a significant interaction between growth response to weed control and altitude, weed control having the greatest effect on lower elevation sites. This large variation in response to weed control on different sites demonstrated in this and other studies (Richardson et al., 1993) highlights the importance of careful site selection during experimental design.

To define the optimal area and duration of weed control, treatment costs must be balanced against value gains at the end of the rotation. Probably the most appropriate method for projecting rotation age growth gains from short-term data is to express the growth gain in terms of a time change (Richardson and West, *in press*; Wilkinson et al., 1992). With the assumption of a parallel growth response (Richarson and West, *in press*), exisiting growth models can be used to calculate the economic impacts of such time changes. However, this method cannot reliably be used with only first year data.

Another approach to this problem is to simply calculate the growth gain at a given age and compare this against treatment cost (Balneaves, 1987; Balneaves and Henley, 1992). Using this method, Balneaves (1987) concluded that on a dry South Island site the optimal spot size per unit of cost was his smallest spot size treatment (1.0 m diameter) even though maximum growth was obtained with complete weed control. A similar calculation would lead to an identical conclusion on the experiments reported here. However, as discussed above, the conclusion ignores the fact that complete weed control would still be more profitable as long as the value of the growth gain exceeded the extra treatment cost. Thus, while this method has merit for comparing treatments at one point in time, it cannot be used to select the treatment that gives the maximum economic return, because even a small increment in growth per unit of cost might be economically justifiable depending on the final value of that growth gain.

Thus, with only one year of data there is no reliable method for quantitatively assessing the optimal spot size. However, until more measurements are taken over time, the growth trend data can still be used to make subjective but practical recommendations based on "threshold" spot sizes i.e. spot sizes beyond which there are either only slight gains in growth or a rapid decrease in the rate of growth gain. At Kinleith it is clear that a spot size between 0.5 and 1 m diameter is all that is required to maximise growth and minimise mortality. At Kaingaora, there is clearly a threshold spot size for maximising height growth at around 1 m. However, with diameter growth, a much more important variable in terms of crop biomass production, there is no clear threshold. It would appear that any spot size between 1.5 and 2.0 m diameter would give a substantial growth benefit. Although significant growth gains continue beyond this spot size range, other benefits resulting from maintaining a herbaceous ground cover would be lost if spot size was increased much beyond this point.

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TABLE 1-Short-term treatments to define the optimal area and duration of weed control

Area of weed control		Duration of weed control (years)			
Diameter (m)	**Area (m^2)**	**1**	**2**	**4**	**7**
0	0	K[1]	-[2]	-	X[3]
1	0.8	X	X	X	-
1.5	1.8	X	X	X	-
2.0	3.1	X	X	X	-
3.0/6.0[4]	7.1/28.3[4]	X	X	X	X

[1] Two treatments applied at Kinleith only - no weed control for 1 year followed by either a 1.5 or 4.0 m diameter weed control treatment maintained for two further years.

[2] No treatment.

[3] Treatment applied at Kaingaroa and Kinleith.

[4] Variable treatments for Kaingaroa/Kinleith respectively, because of different planting spacing.

Table 2-A comparison of requested and actual spot diameter for each treatment and location.

Requested spot diameter (m)	Measured mean spot diameter (m)		
	Kinleith	Kaingaroa short-term	Kaingaroa long-term
0	0.4	0.4	0.3
1	0.7	1.2	1.4
1.5	1.3	1.5	
2	1.9	1.5	1.9
3	-	2.0	3.3
6	5.6		

Table 3: Percentage of the variation in growth at Kaingaroa explained by the regression models

Location	Percentage of variation in growth explained by model	
	Height	Diameter
Kaingaroa short-term	25	37
Kaingaroa long-term	76	93
Kinleith	43	39

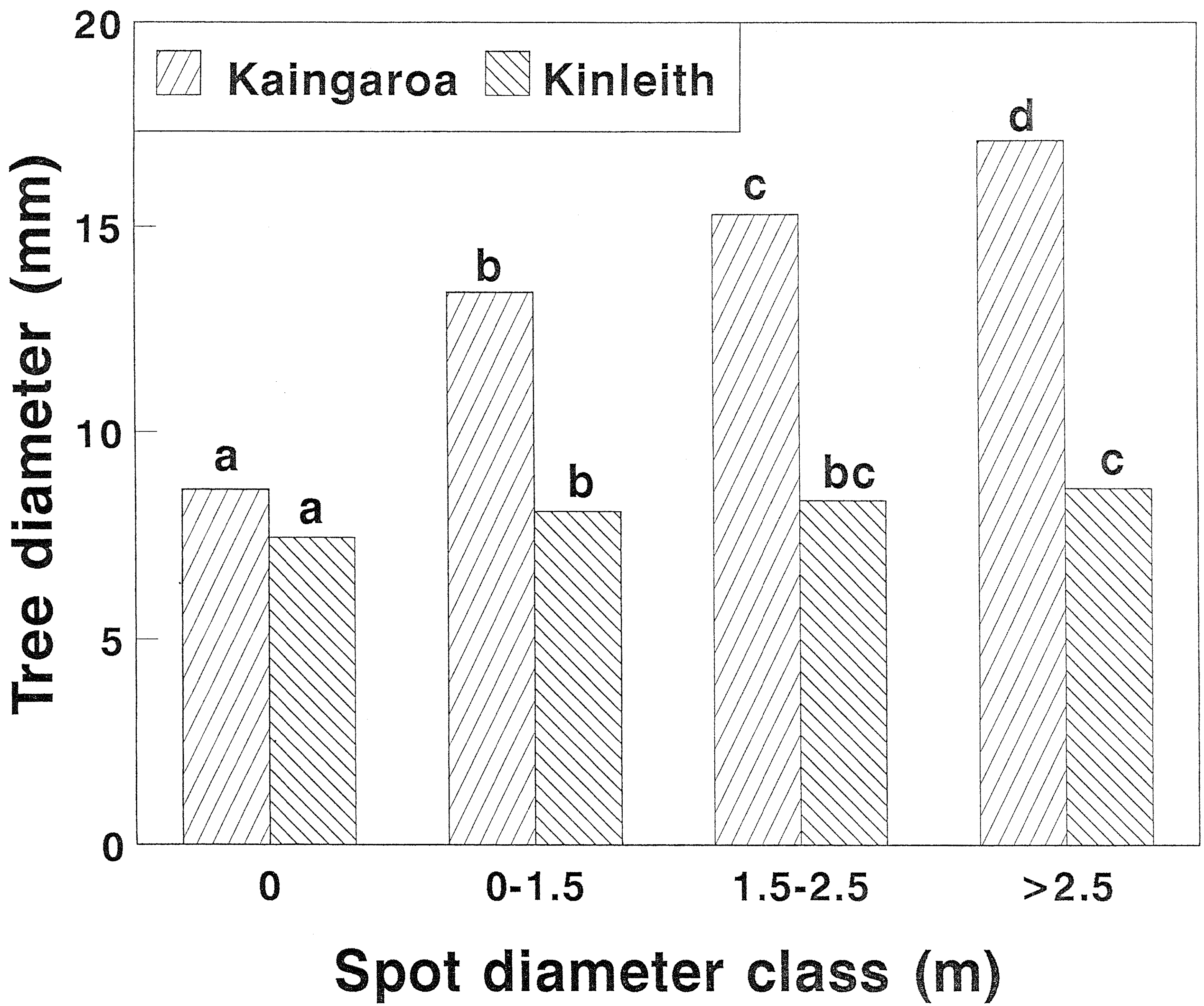
FIG. 1-Radiata pine root-collar diameter one year after planting as a function of weed-free spot diameter class. At a given site, bars topped by the same letter are not significantly different at the 5% level according to Fisher's Protected LSD test.

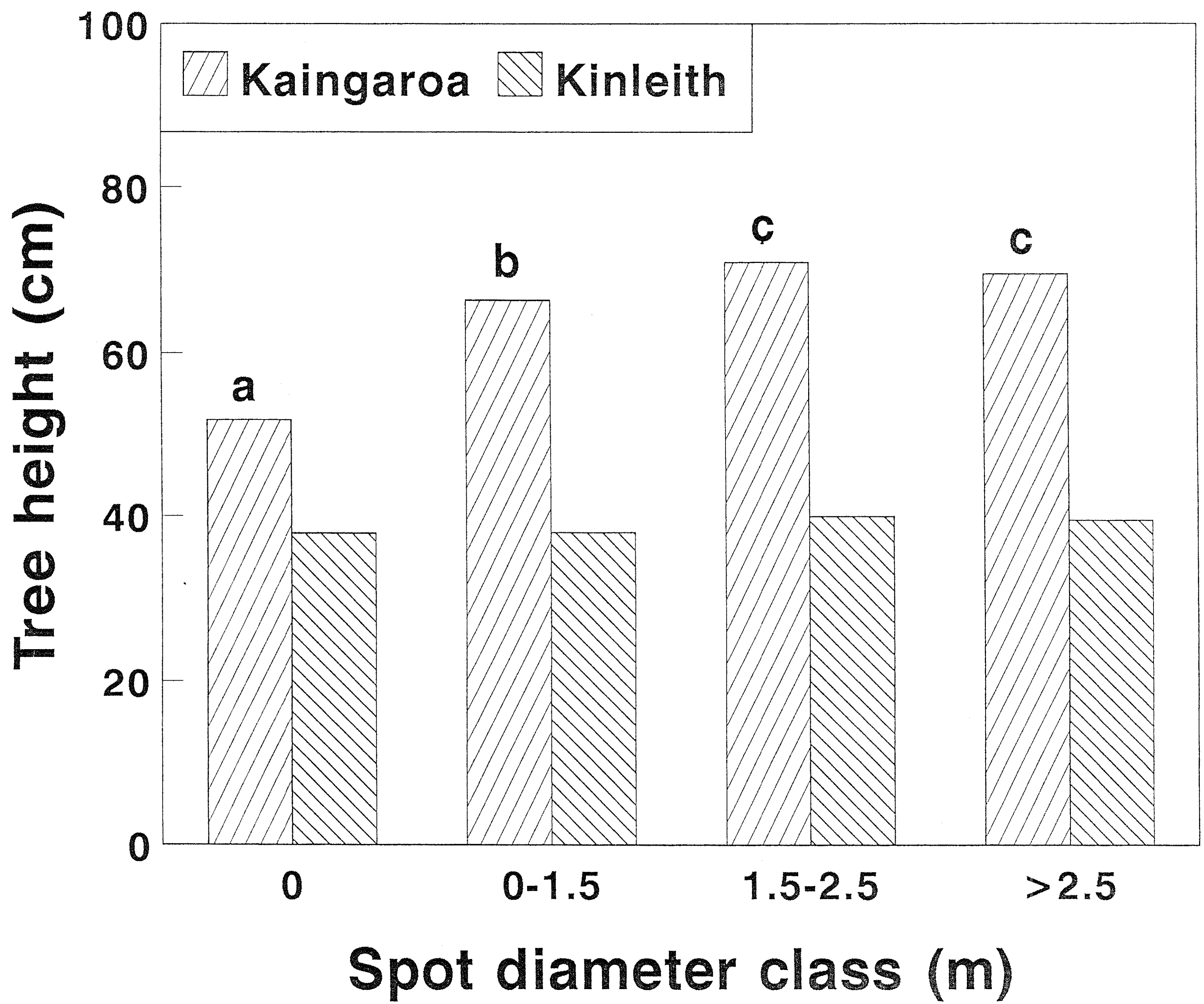
FIG. 2-Radiata pine height one year after planting as a function of weed-free spot diameter class. At a given site, bars topped by the same letter are not significantly different at the 5% level according to Fisher's Protected LSD test.

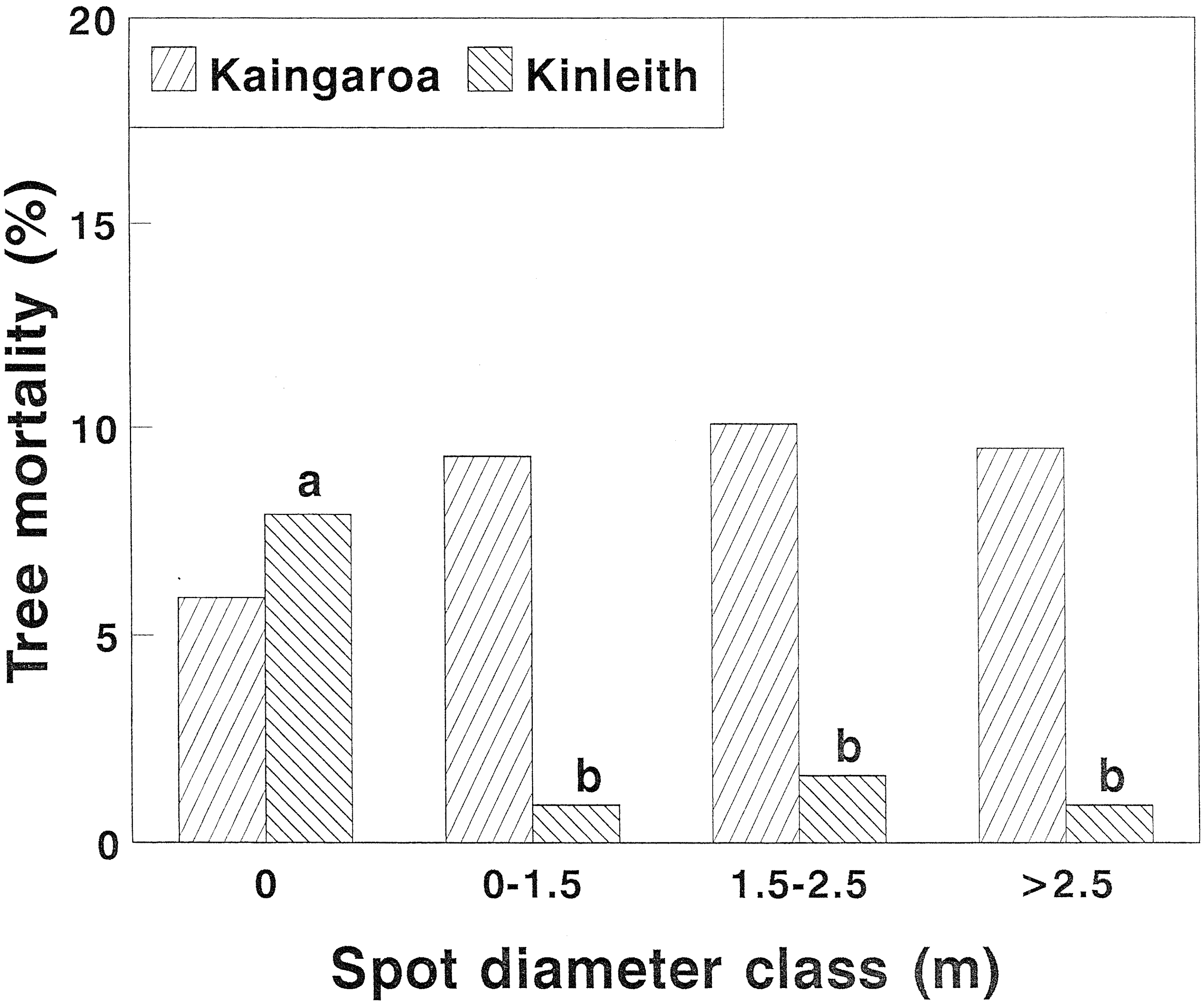
FIG. 3-Radiata pine percentage mortality one year after planting as a function of weed-free spot diameter class. At a given site, bars topped by the same letter are not significantly different at the 5% level according to Fisher's Protected LSD test.

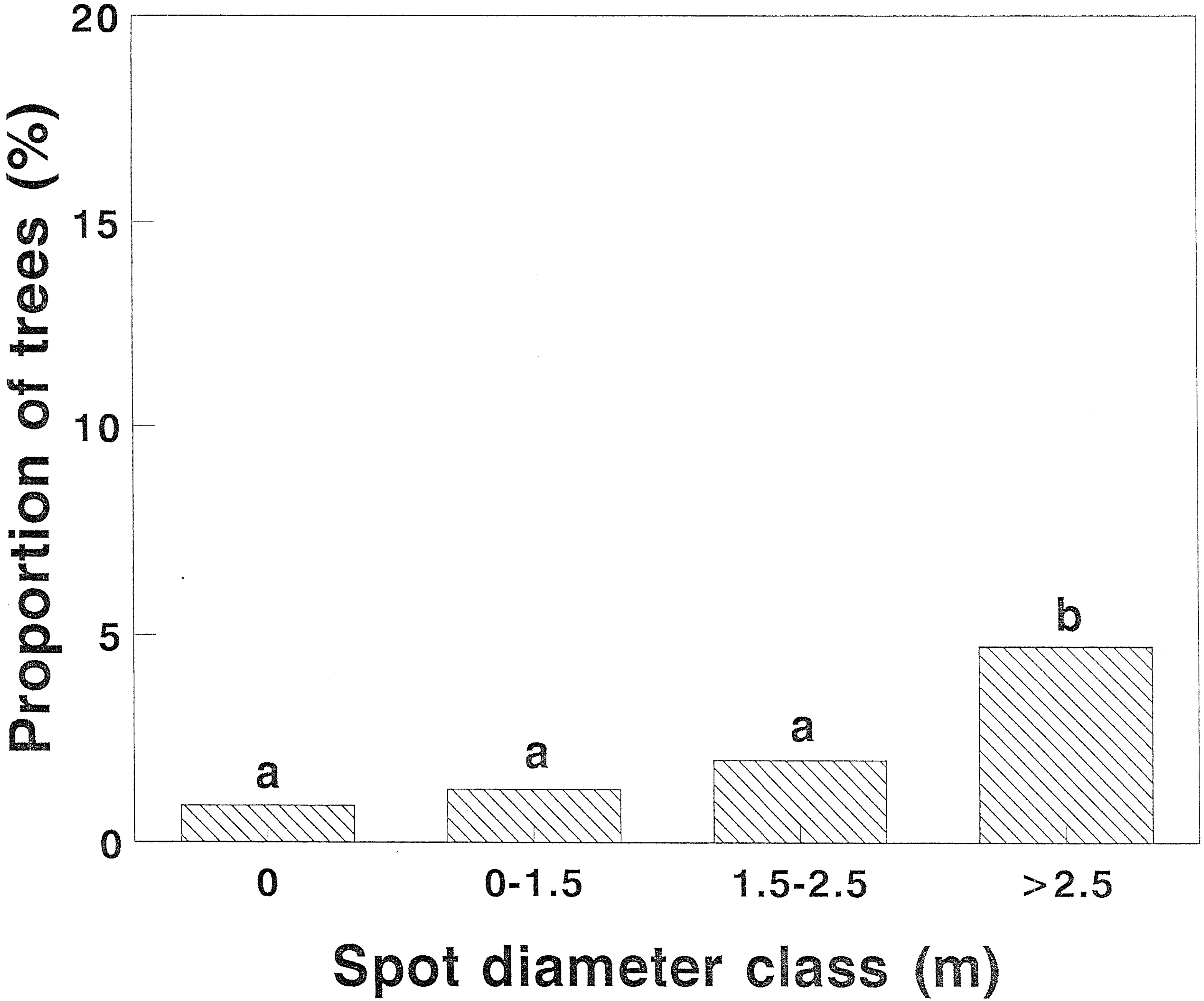
FIG. 4-Proportion of radiata pine on which browsing damage was observed at Kaingaroa. Bars topped by the same letter are not significantly different at the 5% level according to Fisher's Protected LSD test.

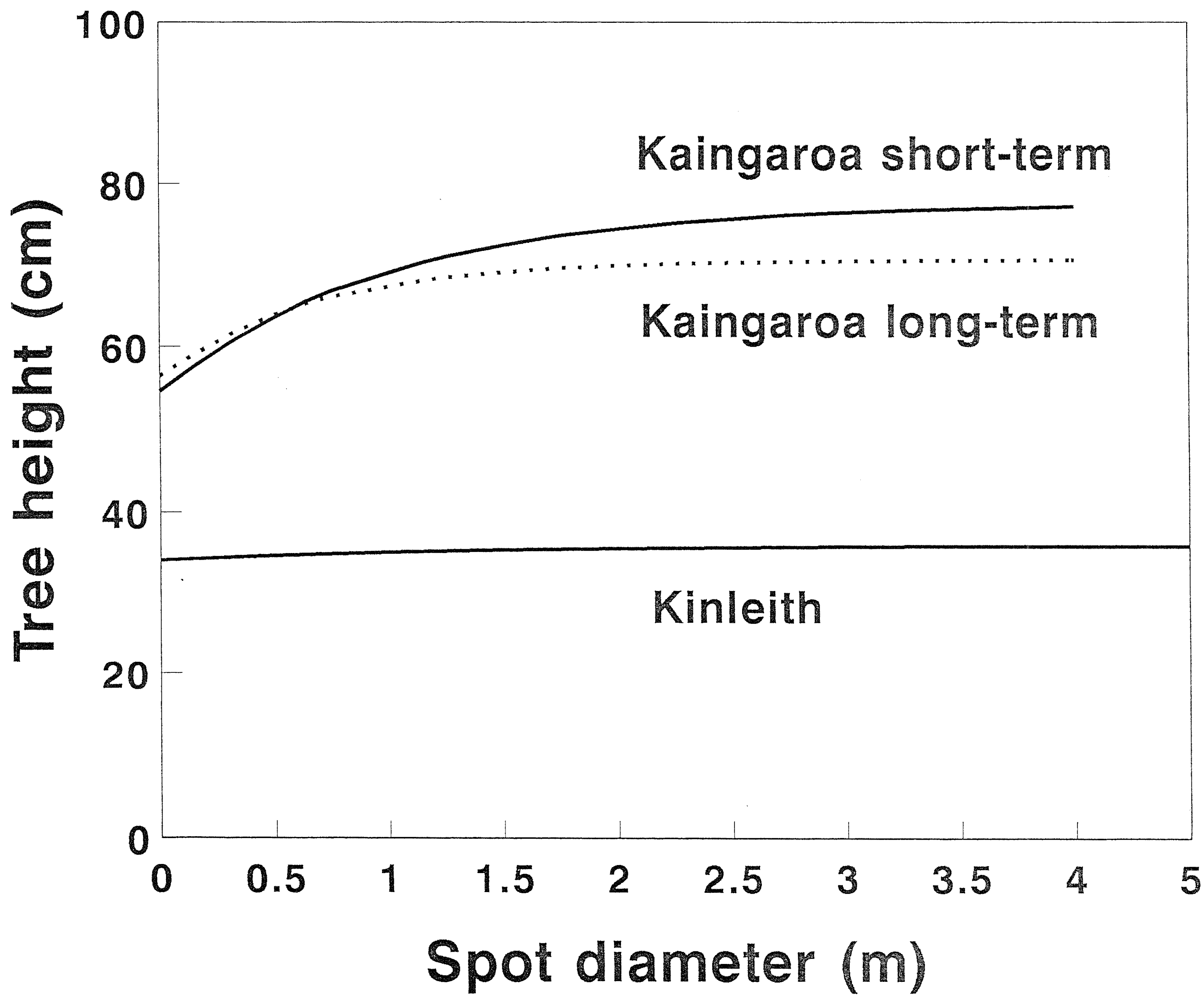
FIG. 5-Predicted radiata pine (a) diameter and (b) height growth one year after planting as a function of weed-free spot size.


Tree diameter (mm)
20
15
10
5
0
Kaingaroa
Kinleith
a
a
b
b
c
bc
d
c
0
0-1.5
1.5-2.5
>2.5
Spot diameter class (m)

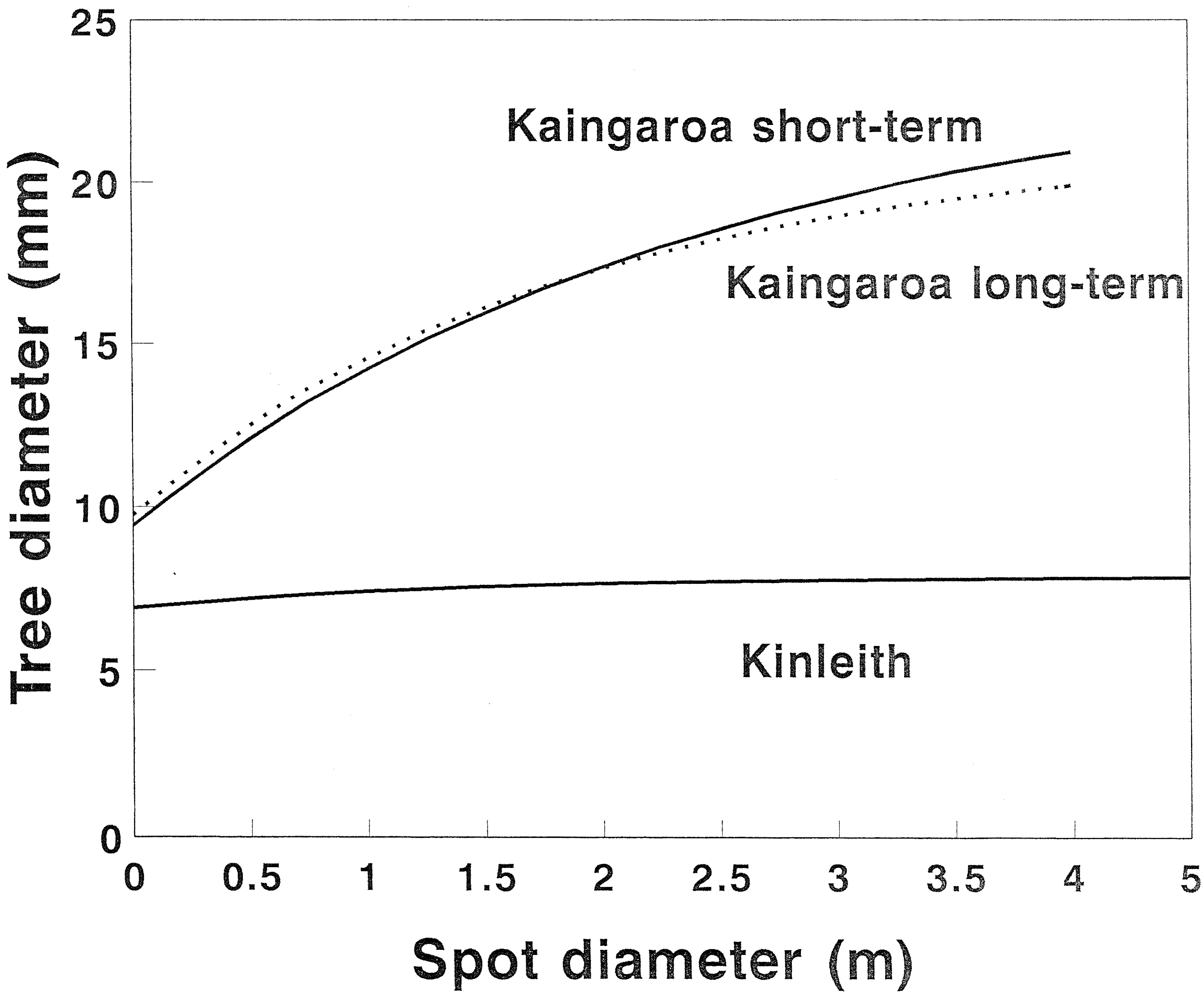

Kaingaroa
Kinleith
Tree height (cm)
100
80
60
40
20
0
a
b
c
c
0
0-1.5
1.5-2.5
>2.5
Spot diameter class (m)


Tree mortality (%)
20
15
10
5
0
Kaingaroa
Kinleith
a
b
b
b
0
0-1.5
1.5-2.5
>2.5
Spot diameter class (m)


Proportion of trees (%)
20
15
10
5
0
a
a
a
b
0
0-1.5
1.5-2.5
>2.5
Spot diameter class (m)



Tree height (cm)
100
80
60
40
20
0
Kaingaroa short-term
Kaingaroa long-term
Kinleith
0
0.5
1
1.5
2
2.5
3
3.5
4
5
Spot diameter (m)


Tree diameter (mm)
25
20
15
10
5
0
0.5
1
1.5
2
2.5
3
3.5
4
5
Spot diameter (m)
Kaingaroa short-term
Kaingaroa long-term
Kinleith