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Mid-Rotation Response of Soil Preparation Intensity and Timing of Weed Control on Radiata Pine †

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Abstract: A good instance to improve the availability of resources for tree planting is during the establishment of stands, increasing the survival and initial growth of plants. Despite the common use of soil preparation, there are uncertainties about its long-term effects on stand growth and the intensity required. Weeds compete with crop plants for site resources, such as light, water, and nutrients, so evaluating the best time to apply this treatment is key. The objective of this study is to quantify the effects of soil preparation intensity and the timing of weed control on the long-term growth responses of radiata pine on a metamorphic soil in Chile. The study was established on a split-plot design with cultivation as the main plot treatment (shovel, subsoiling, and disking) and weed control as subplots (none, pre- and post-, and only post-planting) to remove all competing vegetation. Subsoiling was performed to 80 cm and disking to a 30 cm depth. Trees were planted in 2013 and were measured annually for diameter at breast height (DBH) and total height. Nine years after establishment, soil preparation treatments with weed control applied at pre- and post-establishment showed the lowest mortality. The best responses in cumulative volume were observed for disking and subsoiling plus weed control at pre-establishment, and the lowest responses were observed for treatments not including weed control. Weed control was the key treatment providing good growth response. Interestingly, the hypothesis that deep soil tillage was required on long dry season sites such as these was rejected given that disking to 30 cm provided equal or even larger growth responses.

Keywords: *Pinus radiata*; silvicultural treatments; metamorphic soils

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1. Introduction

Studies have shown that short- and mid-term responses to silvicultural treatments such as tillage, fertilization, and weed control [1–3] may present long-term uncertainty in volume gains according to the site and intensity of application [2,4,5]. Although large responses in stand growth have been reported for weed control application, questions remain about the best timing and duration of application [2,3]. Similarly, for soil preparation, in which short-term gains have been reported [3], mid- and long-term responses raise doubts about the intensity of the application due to inconsistent responses [6], with some

studies even showing null or negative results in the accumulated growth of stands over time [2,7,8]. Therefore, a better understanding of the timing and intensity of application of early silvicultural treatments is required.

Pinus radiata D. Don is one of the most intensively managed and widely planted commercial forest species in the world [9], with significant gains in productivity due to the optimization of silvicultural practices and genetics [10,11]. For this reason, a good knowledge of silvicultural practices applied to this species is required and, thus, helps with decisions and operational cost-benefit analyses.

In the present study, we evaluated mid-rotation growth responses to soil preparation intensity and weed control opportunity applied to *Pinus radiata* stands at establishment. Our hypotheses are: (I) a longer duration of weed control will increase stand survival and growth because the study site has a prolonged dry summer season, and (II) more intensive soil preparation will increase the survival and early growth of radiata pine trees.

2. Materials and Methods

2.1. Site Characteristics

The study was installed as a split-plot design with cultivation as main plot treatment (intensity of soil preparation) and weed control as subplots (opportunity of vegetation control) in 2013 in the city of Quirihue, Región de Ñuble, in the central valley of Chile (Figure 1). The study was established in metamorphic soil with a mean annual temperature of 13 °C and 750 mm yr^{-1} of annual precipitation.

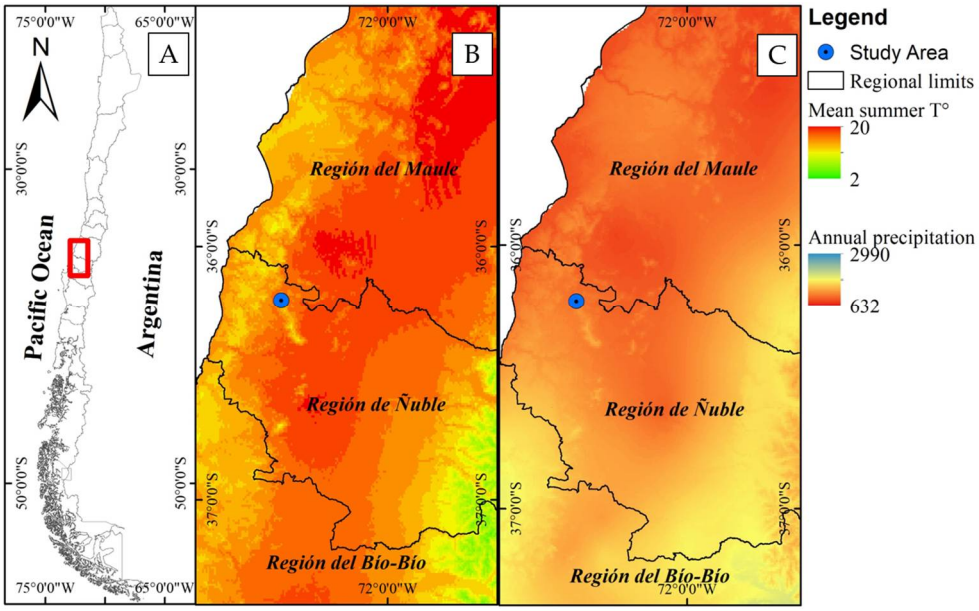

Figure 1. Ubication of trial in Chile (**A**), study area of maps of mean summer temperature (**B**), and annual precipitation (**C**).

Soil preparation was applied in three intensities: shovel (none), disking and subsoiling, and weed control, which was applied in three opportunities: no weed control, weed control post-planting, and weed control pre- and post-planting, resulting in nine final treatments (Table 1).

Table 1. Description of treatments applied in the study.

Treatments	Soil Preparation	Weed Control	Description
Sho	Shovel	Uncontrolled	New Zealand shovel
Sho and WC1	Shovel	Pre- and post-planting	New Zealand shovel, total pre-planting weed control (year 0), and post-planting weed control 1 m (year 1) and 2 m (year 2)
Sho and WC2	Shovel	Post-planting	New Zealand shovel and post-planting weed control 1 m (year 1) and 2 m (year 2)
Disk	Disking	Uncontrolled	Disking (30 cm)
Disk and WC1	Disking	Pre- and post-planting	Disking (30 cm), total pre-planting weed control (year 0), and post-planting weed control 1 m (year 1) and 2 m (year 2)
Disk and WC2	Disking	Post-planting	Disking (30 cm) and post-planting weed control 1 m (year 1) and 2 m (year 2)
Sub	Disk and subsoiling	Uncontrolled	Subsoiling (80 cm) and disking (30 cm)
Sub and WC1	Disk and subsoiling	Pre- and post-planting	Subsoiling (80 cm), disking (30 cm), total pre-planting weed control (year 0), and post-planting weed control 1 m (year 1) and 2 m (year 2)
Sub and WC2	Disk and subsoiling	Post-planting	Subsoiling (80 cm), disking (30 cm), and post-planting weed control 1 m (year 1) and 2 m (year 2)

The 27 plots were planted with *Pinus radiata* plants in August 2013 at 1250 trees ha^{-1} (4 × 2 m spacing). Each treatment plot contained 121 trees (0.09 ha), and the internal measurement plots contained 49 trees (0.0392 ha).

2.2. Annual growth measurements

Diameter at breast height (DBH, at 1.3 m) and total height of radiata pine plants were measured after planting and annually for 9 years (until 2022). We estimated the individual tree volume through a function developed for young radiata pine used by Albaugh et al. [2], Equation (1):

$$V_i = -0.00214 + 0.0000295 \times D^2 + 0.001349 \times H + 0.00002486 \times D^2 \times H \quad (1)$$

where V_i is tree volume (m^3 tree^{-1}), D is DBH (cm), and H is total height (m). Volume per plot (VOL) was calculated summing the individual volume of each tree and scaling plot estimates to a hectare level (m^3 ha^{-1}). Average survival (SURV, %) was calculated for each plot and year as the number of living trees divided by the number of initial plants established.

3. Results and Discussion

At age nine, soil preparation had a significative effect only on stand volume and survival ($p < 0.05$), with the best cumulative volume for disking and subsoiling (92.9 m^3 ha^{-1} and 94.7 m^3 ha^{-1}, respectively) and similar for survival (71 and 74%, respectively, with the lowest survival for shovel with 52%, Table 2).

Table 2. Summary at 9 years after establishment of evaluated treatments and responses (treatment minus only shovel). Treatments correspond to a combination of soil preparation and weed control.

Treatment	DBH			Total Height			Stand Volume			Survival (%)
	Mean (cm)	Response (cm)	Response (%)	Mean (m)	Response (m)	Response (%)	Mean (m^3 ha^{-1})	Response (m^3 ha^{-1})	Response (%)	
Sho	14.1			11.5			21.5			17.7
Sho and WC1	14.9	0.8	5.7	13.5	2.0	17.4	111.6	90.1	419.1	89.1
Sho and WC2	16.1	2.0	14.2	13.2	1.7	14.8	66.1	44.6	207.4	48.3
Disk	14.6	0.5	3.5	11.8	0.3	2.6	54.4	32.9	153.0	52.4
Disk and WC1	15.3	1.2	8.5	14.6	3.1	27.0	133.9	112.4	522.8	93.9
Disk and WC2	15.9	1.8	12.8	13.5	2.0	17.4	90.4	68.9	320.5	66.0
Sub	13.2	−0.9	−6.4	11.5	0.0	0.0	54.3	32.8	152.6	59.9
Sub and WC1	15.5	1.4	9.9	14.3	2.8	24.3	134.2	112.7	524.2	93.9
Sub and WC2	15.8	1.7	12.1	13.8	2.3	20.0	95.6	74.1	344.7	68.7

Weed control had a significative effect on all growth variables (p value < 0.05), with the lowest responses without the application of weed control. The highest survival was found for weed control pre- and post-planting (92%), and weed control post-planting presented a survival mean of 61%; the lowest survival was for no weed control with 43% (Table 2). Our results were similar to other studies that analyzed the effect of weed control as a critical silvicultural treatment at establishment, especially at sites with less water availability [2,12]

No interactions were found at age nine between soil preparation and weed control (p value > 0.05, Table 2).

For individual treatments at age nine, survival was the lowest in the shovel treatment (17%); the treatments with any soil preparation plus weed control applied pre- and post-planting had the highest survival (94%). With respect to growth metrics, the best responses in DBH were in Sho and WC2 (+2 cm), and the lowest response was in Sub (−0.9 cm). The best response on total height was in Sub and WC1 (+2.8 m), and the lowest total heights were in all the treatments of soil preparation without weed control (Table 2).

For stand volume, disk and Sub plus weed control pre-planting had the best responses (133 m^3 ha^{-1}, with a gain of 112 m^3 ha^{-1} with respect to only shovel, Figure 2 and Table 2). Pre- and post-planting weed control showed the best responses in volume and the survival of the stand, regardless of the intensity of the soil preparation applied.

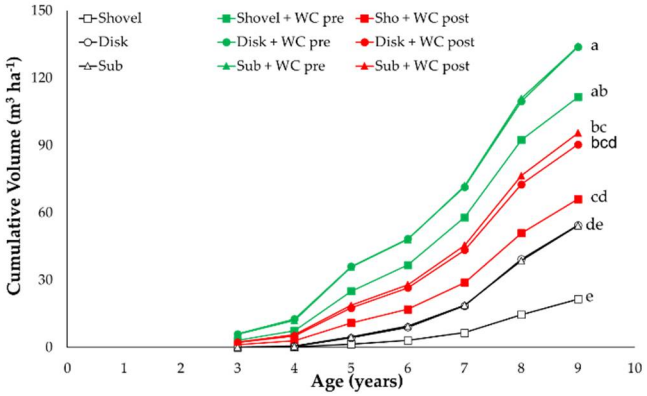

Figure 2. Cumulative stand volume by individual treatments over time. Different lowercase letters to right side of the lines of each treatment represent the significant differences among treatments (Tukey's Honestly Significant Difference (HSD) test, *p* value < 0.05).

4. Conclusions

Weed control was the key treatment providing good growth response over time, like what has been observed in previous trials in Chile. Pre-planting weed control improves survival and provides for a better selection of trees when thinning for sawtimber purposes.

Interestingly, the hypothesis that deep soil tillage (e.g., subsoiling to 80 cm) was required on long dry season sites such as these was rejected given that disking to 30 cm provided equal or even larger responses. The need for a more robust model for soil preparation decisions may be of great value for forest operations.

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