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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 the study is to quantify the effects of soil preparation intensity and timing of weed control on 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+post and only post planting) to remove all competing vegetation. Subsoiling was performed at 80 cm and disking to 30 cm depth. Trees were planted in 2013 and were measured annually for DBH and total height. Nine years after establishment, soil preparation treatments with weed control applied at pre+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 at 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 like these was rejected given that disking to 30 cm provided equal or even larger growth responses.0

Keywords: Pinus radiata; Silvicultural treatments; Metamorphic soils

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1. Introduction

Studies had shown that short and mid-term responses to silvicultural treatments as tillage, fertilization and weed control [1-3] may present long-term uncertainty in volume gains according to 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 inconsistent responses [6], with some studies even show null or negative results in the accumulated growth of stands in the 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 at optimization of silvicultural practices and genetics [10,11]. For this reason, a good knowledge of silvicultural practices applied to this specie is required and thus help in 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 timing 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 a metamorphic soil with a mean annual temperature of 13°C and 750 mm yr^{-1} of annual precipitation.

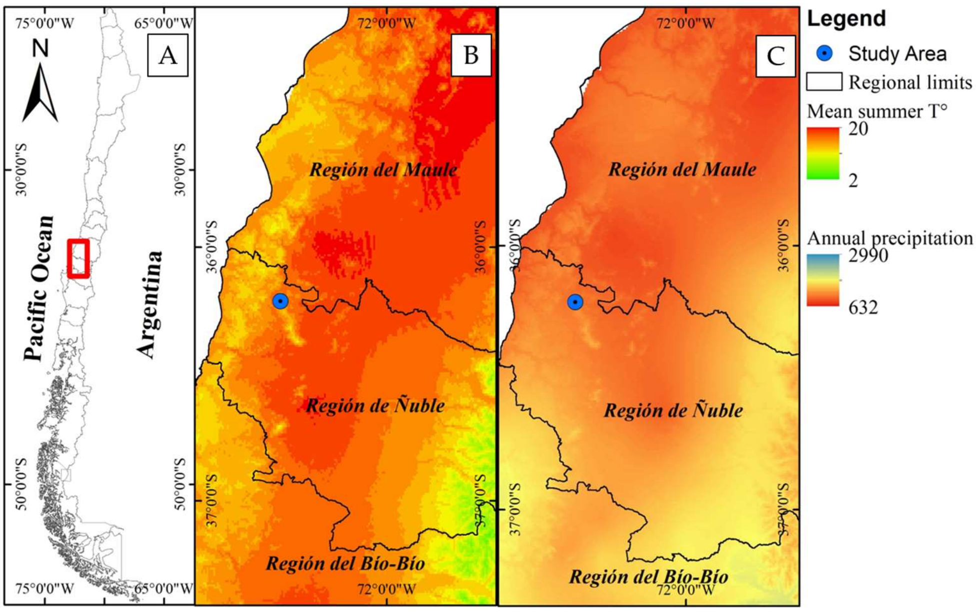

Figure 1. Ubication of trial in Chile (A), and study area on maps of mean summer temperature (B) and Annual precipitation (C).

Soil Preparation was applied on three intensities: Shovel (none), Disking and Subsoiling; and Weed Control was applied on three opportunities: No weed control, weed control post plantation and weed control pre+post plantation, 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+WC1	Shovel	Pre+post planting	New Zealand Shovel, Total Pre-Planting Weed Control (year 0) + Post Planting Weed Control 1m (year 1) + 2m (year 2)
Sho+WC2	Shovel	Post planting	New Zealand Shovel, Post Planting Weed Control 1m (year 1) + 2m (year 2)
Disk	Disking	Uncontrolled	Disking (30 cm)
Disk+WC1	Disking	Pre+post planting	Disking (30 cm), Total Pre-Planting Weed Control (year 0) + Post Planting Weed Control 1m (year 1) + 2m (year 2)
Disk+WC2	Disking	Post planting	Disking (30 cm), Post Planting Weed Control 1m (year 1) + 2m (year 2)
Sub	Disk+subsoiling	Uncontrolled	Subsoiling (80 cm) + Disking (30 cm)
Sub+WC1	Disk+subsoiling	Pre+post planting	Subsoiling (80 cm) + Disking (30 cm), Total Pre-Planting Weed Control (year 0) + Post Planting Weed Control 1m (year 1) + 2m (year 2)
Sub+WC2	Disk+subsoiling	Post planting	Subsoiling (80 cm) + Disking (30 cm), Post Planting Weed Control 1m (year 1) + 2m (year 2)

The 27 plots were planted with *Pinus radiata* plants in August 2013 at 1250 trees ha^{-1} (4 x 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 pines plants were measured after planting, and annually for 9 years (until 2022). We estimated the individual tree volume using:

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

Where V_i is tree volume (m^3 $tree^{-1}$), D is DBH (cm) and H is total Height (m) [12]. Volume per plot (VOL) was calculated summing the individual volume of each tree and scaling plot estimates to an 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=9, Soil Preparation had a significative effect only in 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 on Shovel with 52 %, table 2).

Weed control had a significative effect on all the growth variables ($p < 0.05$), with the lowest responses without application of weed control. The highest survival was found for Weed Control pre+post planting (92%) and Weed Control post planting presented a survival mean of 61 %; and the lowest survival was for No Weed Control with 43 % (table 2). Our results were similar to other studies that analyze the effect of weed control, being a critical silvicultural treatment in the establishment, especially at sites with less water availability [2,13]

No interactions were found at age=9 between soil preparation and weed control ($p > 0.05$, table 2).

For individual treatments at age=9, survival was the lowest in the only shovel treatment (17 %); and the treatments with any soil preparation plus weed control applied pre+post planting had the highest survival (94 %). Respect to growth metrics, the best responses in DBH was on Sho+WC2 (+ 2 cm) and the lowest response was in only Sub (-0.9 cm). The best response on Total Height was on Sub+WC1 (+ 2.8 m), and the lowest Total Height were on all the treatments of Soil Preparation without Weed Control (table 2).

Table 2. Summary at 9 years after establishment of evaluated treatments and responses (Treatment minus only Shovel). Treatments corresponds 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+WC1	14.9	0.8	5.7	13.5	2.0	17.4	111.6	90.1	419.1	89.1
Sho+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+WC1	15.3	1.2	8.5	14.6	3.1	27.0	133.9	112.4	522.8	93.9
Disk+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+WC1	15.5	1.4	9.9	14.3	2.8	24.3	134.2	112.7	524.2	93.9
Sub+WC2	15.8	1.7	12.1	13.8	2.3	20.0	95.6	74.1	344.7	68.7

For Stand Volume, Disk and Sub plus Weed Control pre plantation had the best responses (133 m^3 ha^{-1}, with a gain of 112 m^3 ha^{-1} respect to only Shovel, figure 4, table 2). Pre and post planting weed control showed the best responses in volume and survival of the stand are obtained, regardless of the intensity of the soil preparation applied.

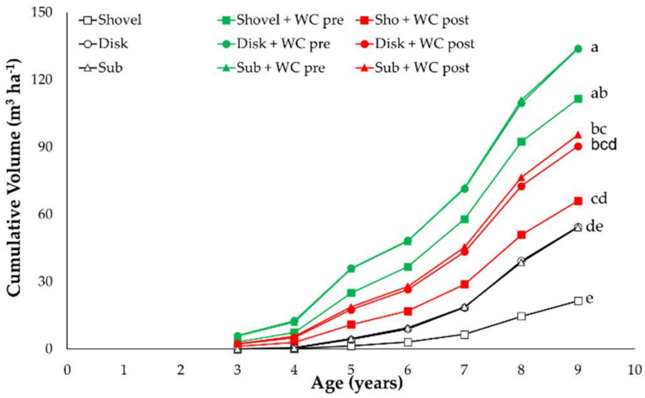

Figure 4. Cumulative Stand Volume by individual treatments over time.

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 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 like 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.

Author Contributions: Contributions for this manuscript consider Conceptualization, RR, DB; methodology, RR, DB, YE, TA; formal analysis, DB, RR; investigation, RR, OC, RC, DB, DC, TA; writing—original draft preparation, DB, RR; writing—review and editing, RR, DB; supervision, RR, OC, RC, DC, TA; project administration, RR, DB, YE, TA. All authors have read and agreed to the published version of the manuscript.

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