Long-term growth response to patterns of weed control in radiata pine

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Summary The long term growth response of radiata pine (*Pinus radiata* D.Don) to different patterns of weed control was evaluated at three second rotation sites in the south east of South Australia. Treatments consisted of ten combinations of nil, spot, strip and complete weed control, applied at pre-planting and 12 months later. Growth responses at four years showed that greatest benefit was achieved by complete weed control at both pre- and post-planting. At 8.5 years this treatment still had the greatest volume growth however there was no significant difference between it and some other treatments. Of these, complete weed control at pre-planting only was the preferred option, as only one herbicide application and less herbicide was required to achieve a similar growth response.

Keywords Weed control, plantation establishment, long-term growth response, *Pinus radiata*.

INTRODUCTION

Weed competition for soil moisture and nutrients during the first two summers after planting can have severe effects on the early growth of radiata pine (*Pinus radiata* D.Don) in the south east of South Australia. As little as 5–10% weed cover on dry sandy soils can result in reduced growth as a result of water stress (Nambiar and Zed 1980). As a result, plantation establishment silviculture in the region is strongly focused on reducing weed competition. Internal ForestrySA research programs have reflected, and continue to reflect, that focus.

Weed control trials for plantation establishment are generally short term in nature, rarely exceeding 4–5 years. Such time frames are generally sufficient to provide forest managers with the information required to achieve successful plantation establishment but are less likely to provide information suitable to compare the cost/benefit of different weed control options for crops with long rotations such as *P. radiata*.

During the 1980s ForestrySA (then Woods and Forests Department) commonly used hexazinone (Velpar®) and atrazine (Gesaprim®) to provide effective residual weed control. These herbicides were applied at pre-planting and 12 months later as complete or, less often, strip applications. Questions regarding the longevity of growth responses to, and the economic implications of, different patterns of weed control led to the establishment, during 1989/1990, of a long-term experiment on three second rotation (2R) *P. radiata* sites.

MATERIALS AND METHODS

Site location and history Trials were established at three second rotation sites on shallow (0.5–1.0 m) podsolised sands in the south east of South Australia (Table 1). An initial site was established in 1989 near Penola. A further two sites were established in 1990 near Mt. Gambier and Mt. Burr. Tree seedlings were planted at 2.5 m × 2.5 m spacing (1600 trees ha^{-1}). Fertiliser was applied, in accordance with normal ForestrySA practise, during the first three years after planting at Penola and Mt. Burr. Mt. Gambier, being more fertile, did not receive additional fertiliser. Rabbit and grasshopper control was undertaken in 1990 and 1991 at the Mt. Gambier site. Mt. Burr also received a pre-plant application of metsulfuron methyl (9 g a.i. ha^{-1}) applied as Brushoff® to control sorrel (*Acetosella vulgaris* Fourr.).

Experimental design A randomised complete block design, comprising four blocks of 10 plots, was used at each site. Herbicide treatments were applied to large plots (25 m × 25 m) containing 100 trees. Within each treatment plot two buffer rows surrounded an internal measurement plot of 36 trees. Treatment details are provided in Table 2.

Table 1. Site details.

	Penola	Mt. Gambier	Mt. Burr
Rainfall (1st y)[A]	670	673	665
Rainfall (8.5 y)	6104	6095	6260
Soil classification[B]	Wandilo Sand	Mt. Burr Sand	Mt. Burr Sand
Previous site Quality[C]	V/VI	I/II	V/VI

[A] 10 month period to end of first summer.
[B] Stephens *et al*. (1941).
[C] Site Quality Classes range from I–VII with I having the highest productivity and VII the lowest (Lewis *et al.* 1976).

Herbicide application Herbicide treatments were applied using a combination of hexazinone (1.5 kg a.i. ha^{-1}) and atrazine (5 kg a.i. ha^{-1}) with strip and complete treatments applied as Velpar and Gesaprim in 300 L water ha^{-1}. All pre- and post-plant complete applications were by tractor boomspray. Pre-plant strips were applied by tractor boomspray at Penola and Mt. Gambier but there were problems with accuracy because of uneven terrain, stumps and slash. To avoid further inaccuracy pre-plant strips at Mt. Burr and all post-plant strips were applied using a Solo knapsack. Spot treatments were applied as Forestmix granules using a 'weed-a-meter' applicator to supply per hectare rates of hexazinone and atrazine equivalent to strip and complete rates. Inaccuracies occurred in spot placement, relative to tree location, at Penola because planting occurred before treatment effects were evident. Pegging the tree positions greatly improved accuracy of spot placement at the remaining sites. Planned strip and spot dimensions were 1.5 m width and 1.2 m diameter, respectively.

Measurements Weed cover, expressed as percentage of ground cover, was assessed for each weed species in May/June prior to pre-plant herbicide applications, during mid-summer after planting and again in the following spring/summer. The untreated and treated areas within strip and spot treatments were assessed separately. Accuracy of placement and dimensions of pre-plant spot and strip applications were also measured.

Tree survival was assessed at age one and two years. Tree height and diameter were measured annually for the first four years (five at the Penola site), with a later measurement at age 8.5 years.

Data analysis Total stem volumes were calculated for each measurement using ForestrySA volume equations. The stem volumes at each measurement were tested for significant differences between treatments using GENSTAT's analysis of variance routine (ANOVA). Least significant differences values were also calculated at $P<0.05$.

RESULTS

Weed cover During the first two years there were clear differences in weed density between the three sites. Initial weed density was much higher at Penola (30%) than at Mt. Gambier (6.7%) or Mt. Burr (6%). During the summer immediately after planting weed density in untreated areas at Mt. Gambier rose to 36%, exceeding the other sites by three to four times. In the following summer untreated areas at Mt. Gambier were even higher (40–70%) compared with Penola (8–16%) and Mt. Burr (11–22%). Post-plant weed density within strip and complete treated areas was also much higher at Mt. Gambier than at the other two sites. Despite large site differences in pre- and post-plant weed density treatment ranking of growth response was similar across the three sites.

Flatweed (*Hypochoeris radicata* L.) was recorded at all three sites. Clover and grasses occurred at the Mt. Gambier and Mt. Burr sites while sorrel was also present at the Mt. Gambier site. Within treated areas pre-plant spot treatments generally had the best weed control and strip the worst.

Tree survival Early tree survival was poorest for treatments that received no pre-plant weed control (Table 3). Pre-plant spot treatments at Penola had poorer survival than at other sites where survival was comparable with pre-plant strip and complete weed control treatments. While most mortality occurred during the first year of growth, survival at Penola decreased further where there was no post-plant herbicide following pre-plant nil, spot or strip applications.

Table 2. Treatment details.

Treatment	Pre-plant	Post-plant
N-N	Nil	Nil
Sp-N	Spot	Nil
St-N	Strip	Nil
C-N	Complete	Nil
N-C	Nil	Complete
Sp-Sp	Spot	Spot
Sp-C	Spot	Complete
St-St	Strip	Strip
St-C	Strip	Complete
C-C	Complete	Complete

Table 3. Tree survival (%) at two years.

Treatment	Penola	Mt. Gambier	Mt. Burr
N-N	67	90	84
Sp-N	93	98	97
St-N	96	96	99
C-N	99	94	100
N-C	85	95	81
Sp-Sp	90	96	96
Sp-C	94	97	98
St-St	97	96	98
St-C	96	96	98
C-C	99	97	98

Tree growth Total stem volumes at age 8.5 years are presented for selected treatments in Figure 1. Mt. Gambier was the most productive site, where even the poorest treatment (N-N) exceeded volumes achieved in the best treatments at other sites. Total stem volumes for all treatments at age four and 8.5 years are presented in Table 4.

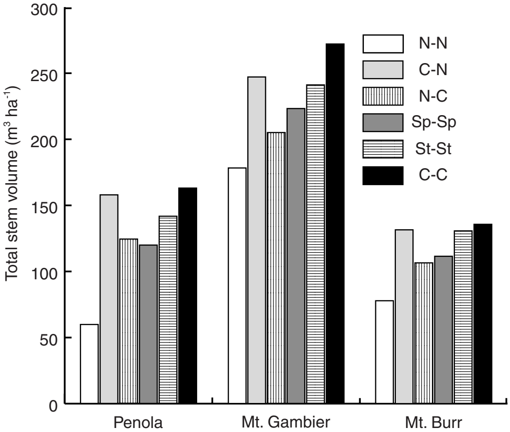

Figure 1. Total stem volume at age 8.5 years.

Table 4. Total stem volume (m^3 ha^{-1}) at 4 and 8.5 years.

	Penola	Mt. Gambier	Mt. Burr
		Age 4 years	
N-N	0.74 a*	8.99 a	1.50 a
Sp-N	3.82 ab	25.88 d	7.48 b
St-N	4.13 ab	20.26 b	12.16 c
C-N	19.82 f	30.97 e	16.50 de
N-C	7.50 bc	18.22 b	8.31 b
Sp-Sp	6.73 bc	25.45 cd	8.33 b
Sp-C	10.87 cd	31.64 e	14.07 cd
St-St	12.72 de	24.96 c	15.37 de
St-C	16.05 ef	29.25 de	16.99 ef
C-C	26.90 g	40.57 f	19.91 f
		Age 8.5 years	
N-N	59.9 a	178.2 a	77.7 a
Sp-N	99.0 b	217.5 bc	104.1 b
St-N	98.0 b	226.9 bcd	122.7 cd
C-N	157.8 d	247.1 cde	131.5 de
N-C	124.3 bc	205.1 ab	106.5 b
Sp-Sp	119.8 bc	223.1 bcd	111.5 bc
Sp-C	148.3 cd	248.9 de	129.5 de
St-St	141.8 cd	241.0 cd	130.7 de
St-C	147.1 cd	256.0 e	121.7 cd
C-C	163.1 d	272.0 e	135.7 e

* values followed by the same letter indicate no significant difference at P<0.05.

In general, greater benefits accrued when weed control was applied earlier during plantation establishment or as the treated area surrounding each tree increased. Where only one year of weed control was applied, volume growth was significantly greater when weed control was applied at pre-planting rather than post-planting. Volume response was greater for complete weed control compared to spot or strip, which were, in turn, greater than nil control. Complete weed control at pre- and post-planting performed best at all sites from an early stage, although the relative benefits over other treatments had declined by 8.5 years. Maximum volume difference between the best and worst treatment was approximately 100 m^3 ha^{-1} at Penola and Mt. Gambier (Figures 2A and 2B) while at Mt. Burr it did not exceed 60 m^3 ha^{-1} (Figure 2C). At 8.5 years volume differences between the best treatment (C-C) and other high performing treatments were still increasing at Mt. Gambier but at Penola and Mt. Burr differences had peaked as early as four or five years and were either stable or declining. At the Penola site

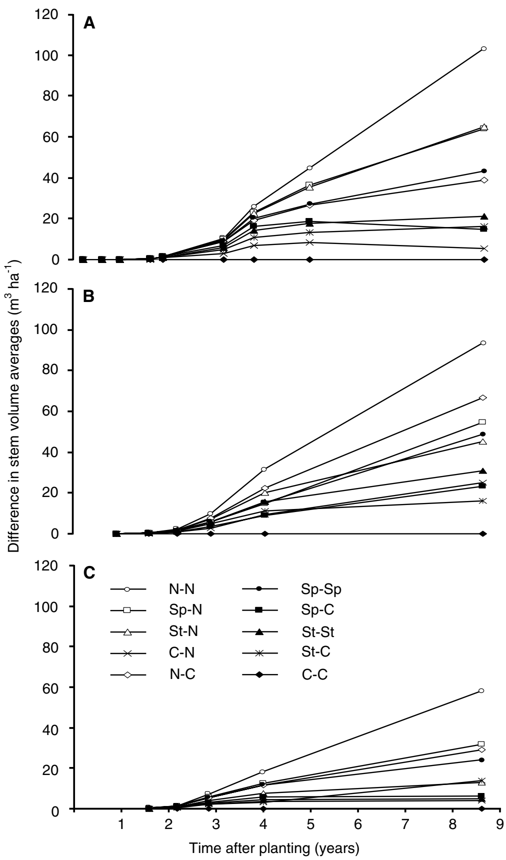

Figure 2. Differences in average stem volume.

the maximum volume difference (8.5 $m^3 ha^{-1}$) between the two best treatments (C-C and C-N) was recorded at five years. By 8.5 years it had dropped to 5.3 $m^3 ha^{-1}$ and was no longer significant.

DISCUSSION

Early, intensive control of herbaceous weeds and grasses can provide long-term growth benefits to *P. radiata* plantations in south east South Australia, even where weed density is relatively low. At Penola and Mt. Burr volume at 8.5 years increased significantly in all herbicide treatments compared to nil weed control.

The importance of early, and accurate, weed control is best illustrated by the tree survival results. Survival was lowest where no pre-plant weed control was applied, especially at Penola and Mt. Burr. At Penola, tree survival was so low (67%) that, if it had occurred in an operational situation, total replanting of the affected area would have been required. There were difficulties in achieving accurate spot and strip applications at the Penola and Mt. Gambier sites. Sub-optimal survival in pre-plant spot treatments at Penola, where accuracy was poorest, reflected this. Inaccuracies in strip applications were attributed to uneven terrain and the presence of slash and stumps from the previous rotation. However, conditions were not unduly rough and generally representative of most second rotation sites available for re-establishment by ForestrySA. Achieving greater accuracy under operational conditions would be unlikely.

Early growth responses (at four years) showed that the greatest benefit was achieved by the most intensive treatment, complete weed control at pre- and post-planting. The treatment also ranked highest at 8.5 years however, there was no significant difference between it and the next best treatments. Of these, complete weed control at pre-planting only, provided the best outcome, for a number of reasons. Weed control occurred early in the establishment period, and with high levels of accuracy, resulted in optimal early tree survival and growth. Only one herbicide application was required, compared to other high performing treatments (C-C, St-C, Sp-C and St-St), resulting in less herbicide required to achieve similar growth by 8.5 years. A full economic analysis is planned to confirm which treatment provided the best economic benefit and will include final volume measurements for age 13 years (to occur in 2002 and 2003).

This research demonstrates the long-term importance of effective weed control during *P. radiata* establishment in this region. It also indicates there is potential to reduce the spatial and temporal intensity of weed control without sacrificing volume production, providing both environmental and economic benefits. The relationship between site quality, weeds and the intensity of weed control (pattern, timing and duration) requires further investigation. The value of long-term silvicultural experiments is highlighted.

ACKNOWLEDGMENTS

The authors thank ForestrySA Research technicians Andrew Cameron, Wayne Richardson, Gordon Conlon, Adrian Agars, Neil Winkley and Grant Sullivan for assistance with establishment and field measurement of the experiment.

REFERENCES

Genstat 5 Release 4.1 4th Edition (1998). Rothamsted Experimental Station, Hertfordshire, England.

Lewis, N.B., Keeves, A. and Leech, J.W. (1976). Yield regulation in South Australian *Pinus radiata* plantations. *Woods and Forests Dept. Bulletin* 23, pp. 174.

Nambiar, E.K.S. and Zed, P.G. (1980). Influence of weeds on the water potential, nutrient content and growth of young radiata pine. *Aust. For. Res.* 10, 279-88.

Stephens, C.D., Crocker, R.L., Butler, B. and Smith, R. (1941). A soil and land use survey of the hundreds of Riddoch, Hindmarsh, Grey, Young and Nangwarry, County Grey, South Australia. CSIRO (Aust.) Bull. No. 142.