Determining the effect of increasing vegetation competition through fertiliser use on the establishment of wildings in unimproved high country grassland

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Abstract

The spread of introduced conifers is causing concern in many parts of New Zealand, particularly the unimproved grasslands of the South Island high country. Many local District Councils require prospective tree planters to apply for a Resource Consent, a major condition of which is full consideration of the risk of wilding spread occurring outside the planted area. Competition from other plants is known to influence the seed germination and establishment of wilding conifers. A trial was established in unimproved high country grassland at Mt Barker, near Lake Coleridge in the Rakaia catchment, central Canterbury. The aim was to determine the effect of vegetation competition enhanced by fertilisers on the emergence of nine introduced conifer species - Lodgepole or contorta pine (*Pinus contorta*), Scots pine (*P. sylvestris*), Corsican pine (*P. nigra*), dwarf mountain pine (*P. mugo*), radiata pine (*P. radiata*), ponderosa pine (*P. ponderosa*), Maritime pine (*P. pinaster*), European larch (*Larix decidua*) and Douglas-fir (*Pseudotsuga menziesii*). Fertiliser, in the form of diammonium phosphate, applied at the rate of 100kg N/ha, increased dry matter production from 255 g/m^2 to 544 g/m^2 two years after application. Over 4 years, the increased vegetation cover caused by the addition of fertiliser had a significant negative effect ($p < 0.01$) on the seedling emergence of all species. The average suppression was 42%, ranging from 28% (maritime pine) to 70% (contorta pine). There was a negative relationship between seed weight and amount of suppression. For the majority of conifers, most seedling emergence occurred in the first year and was largely completed by year 2, with little additional emergence in year 3, and especially year 4.

In a number of locations where introduced conifers grow well, there will always be some spread risk, requiring a commitment to the removal of wilding trees. The Mt Barker trial indicates that fertilisers could be used to increase the competition from existing vegetation and significantly lower wilding numbers, and hence control costs.

1. Introduction and Background

The spread of introduced conifers is causing concern in many parts of New Zealand, particularly the unimproved grasslands of the South Island high country (Department of Conservation, 2001). Many local District Councils require prospective tree planters to apply for a Resource Consent, a major condition of which is full consideration of the risk of wilding spread occurring outside the planted area (Ledgard *et al*. 1997). A range of biotic factors are known to influence the seed germination and establishment of wilding conifers in New Zealand (Ledgard, 2001). One of the most important factors influencing establishment is competition from other plants. A number of researchers have explored aspects of this influence, which are usually most critical during the first 1-2 years after seed dissemination (Cattaneo, 2002, Ledgard, 2004).

Observations have shown that establishment from seed of the major New Zealand introduced conifers is highest on mineral soil and on lightly vegetated sites. Establishment success declines with increasing vegetation cover, stature or density. Watt (1986) found frequent, aggressive and fast growing Lodgepole or contorta pine seedlings at sites with a sparse, short vegetation cover. Numbers were reduced in taller shrubland, and none were found under closed forest canopies. Allen and Lee (1990) observed that contorta pine seedlings established best where scattered tall tussock grasses sheltered sites partially vegetated with grasses and flatweeds. Seedling numbers declined rapidly as density of tussock and surrounding grassland vegetation increased. Benecke (1967) followed the survival of 1-year-old contorta pine seedlings in dense, improved (fertilised) grassland and in partially-open unimproved grassland. After 18 months no seedlings survived in improved (fertilised) grassland, whereas 94% survived in the unimproved grassland. Davis (1989) direct drilled contorta pine seed into improved (sown and fertilised) and unimproved grassland. Of the viable seed, 47% germinated to young seedling stage. In improved grassland none survived to the end of the first season, except where a herbicide treatment was added, which improved survival to 75%. Seedling survival in unimproved grassland was 100%. In another high country trial in unimproved grassland, Davis *et al.* (1996) found that fertiliser application significantly depressed seedling numbers of Corsican and radiata pine after seed sowing with an experimental drill.

The above studies suggest that vegetation manipulation might be used as a tool to assist in the control of wildings. However, most studies have dealt with contorta pine, and there is little New Zealand information on the effect of increased competition on the establishment of other introduced conifer species.

The objective of this study was to compare the effect of vegetation competition improved by fertilisers on the establishment of nine introduced conifer species, sown as seed into unimproved high country grassland.

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2. Methods

2.1 Site

The trial site was at 620 m elevation on a flat terrace beneath Mt. Barker in the Rakaia catchment, Canterbury (grid reference NZMS K35 964602). The Acheron soil is stone-free and of moderate depth (20-40 cm) over greywacke moraine till. Annual pecipitation at Lake Coleridge homestead (520 m, 1.5 km distant) is 907 mm. The vegetation, covering 100% of the trial area, consisted of unimproved short 'grassland' dominated by hawkweeds (mainly *Hieracium pilosella*), hard tussock (*Festuca novae-zelandiae*), browntop (*Agrostis capillaris*) and moss (mainly *Racomitrium* spp.), with a component (about 20%) of low stature woody species (mainly *Leucopogon frazeri* and *Coprosma petrii*). Apart from the hard tussock, very little of the vegetation cover exceeded 50 mm in height.

2.2 Treatments

Species: The species involved in the trial were contorta pine (*Pinus contorta*), Scots pine (*P. sylvestris*), Corsican pine (*P. nigra*), dwarf mountain pine (*P. mugo*), radiata pine (*P. radiata*), ponderosa pine (*P. ponderosa*), Maritime pine (*P. pinaster*), European larch (*Larix decidua*) and Douglas-fir (*Pseudotsuga menziesii*). All these species can be found spreading in the South Island high country (Ledgard, 1988). A sample of 300 seeds of each species was tested for viability in growth chambers prior to sowing in the field - viability ranged between 80 and 100%.

Fertiliser: The two fertiliser treatments were:

- Control - no fertiliser.
- Fertiliser - one application of fertiliser (diammonium phosphate @ 100kg N/ha), applied 2 weeks after seed sowing.

In addition, two vegetation-free treatments (plus and minus fertiliser) were included at the time of trial establishment. However, these were later abandoned and not included in the analyses, due to excessive seed displacement and germination disruption - probably as a result of raindrop impact and rapidly-changing extremes of surface temperature and moisture.

Figure 1. The control (foreground left) and fertilised plots (foreground right). The vegetation-free plots (background) were later abandoned and not included in the analyses. Note also, the netting used as protection from animal browse, and the 50 x 50 cm sampling quadrat (back right), within which the nine conifers were sown in 10 x 10 cm subplots.

2.3 Seeding subplots and sowing

Within the centre of each treatment plot (1 x 1 m), a 50 x 50 cm sampling quadrat, internally divided into twenty-five 10 x 10 cm subplots, was placed, and the top left and bottom right corners permanently located with pegs. Ten seeds of each species were sown in the centre of every second subplot, so that there was an unsown subplot alongside every seeded subplot. The nine species plus unseeded 'control' were allocated randomly to the subplots. Sowing took place in October, 2001. After sowing, the seeds were lightly 'worked' by hand into the vegetation, mainly to stop wind blow into adjacent plots.

2.4 Protection from rabbits and birds

Immediately after sowing, bird netting was placed over every plot (Figure 1), and secured in place by metal pegs.

2.5 Trial layout

The trial was laid out in a randomised-block design, with each block (2 x 2 m) forming one replication containing the fertilised and unfertilised (control) plot treatments randomly located. Each block was replicated 30 times.

2.6 Assessments

Vegetation growth. Vegetation productivity was sampled by means of dry matter clips taken at the end of the second growing season. Randomly selected samples (100 mm x 100 mm) were taken from fifteen unfertilised and fifteen fertilised plots. Samples were sorted into vascular (monocotyledon, dicotyledon, woody) and non-vascular (moss) components before oven drying and weighing.

Conifer seedling emergence. Searches for seedlings were carried out in the autumn of the first growing season after sowing (2002), and then every autumn thereafter for 4 years. At each assessment all counted seedlings (dead and alive) were removed.

2.7 Analysis

A logistic regression model was used to analyse the proportion of sown seed that emerged during the course of the trial. The model was fitted using the SAS procedure GENMOD with the dispersion parameter estimated by the mean deviance to allow for over-dispersion. The model contained factors representing replication, species, fertiliser treatment (fertilised versus unfertilised), and the interaction between species and fertiliser treatment. F-tests of model terms and means and standard errors of emergence proportions were obtained from the model.

To adjust for seed viability, the emergence proportions P were divided by the viability proportion V for each species. As viability proportions were obtained using 300 seed from each species, their standard errors were calculated from the binomial distribution as $se(V) = \sqrt{(V(1-V)/300)}$. To estimate standard errors of emergence proportions adjusted for seed viability, the standard errors of the unadjusted proportions, se(P), obtained from the logistic regression, were combined with the standard errors of the viability proportion, se(V), using the standard formula for the variance of a ratio, i.e., $\sqrt{(se(P)^2/V^2+P^2se(V)^2/V^4)}$.

3. Results

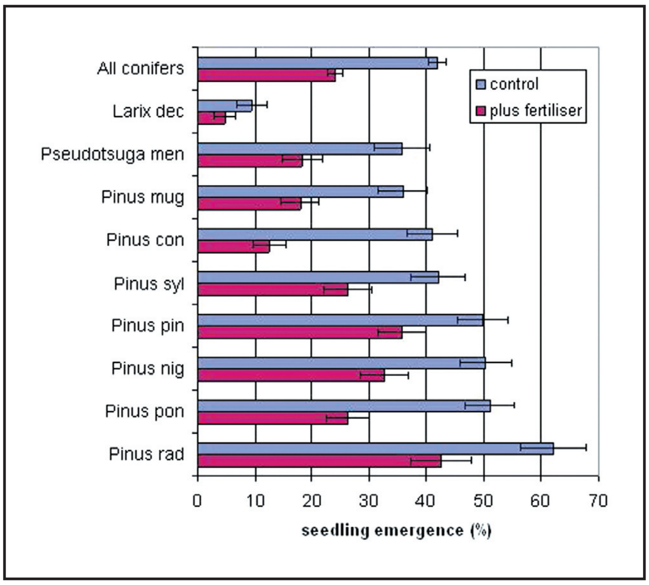
3.1 Effect of fertiliser on vegetation growth

Two growing seasons after fertiliser addition, total vascular plant production in the control plots was 255 g/m2 and 544 g/m2 in the fertiliser treatments - an increase of 110%. The increase in monocotyledon and dicotyledon cover was very similar, at 121% and 108% respectively. The main monocot species were browntop and hard tussock, whilst the dominant dicots were hawkweeds. Woody plant cover increased by 66%. There was no significant effect of fertiliser on moss cover.

3.2 Effect of vegetation competition on seedling emergence

The logistic regression indicated that fertilising significantly reduced emergence of all species ($p<0.0001$), and that there were significant differences in emergence between species ($p<0.0001$). However, there was no significant interaction between species and treatment ($p=0.44$) indicating that the effect of fertilisation on the reduction in emergence was similar across all species. Mean emergence percentage for each species x treatment combination adjusted for seed viability is shown in Figure 2 below.

Figure 2. The mean seedling emergence (adjusted for seed viability) of all conifers and the nine species individually 4 years after sowing with and without one application of fertiliser. Bars show standard errors.



Average seedling emergence over 4 years was 42%, ranging from 62.1% for radiata pine down to 35.8% for Douglas-fir and 9.5% for European larch. The average reduction of seedling emergence caused by fertiliser addition was 43%. The largest reduction was shown by contorta pine (70%), followed by larch (51%), dwarf mountain pine (50%), Douglas-fir (49%), ponderosa pine (48%), Scots pine (37%), Corsican pine (35%), radiata pine (31%) and maritime pine (28%).

3.3 Sequence of seedling emergence

Seedling emergence in the unfertilised plots, as a percentage of viable seed sown, for all conifers over 4 years is given in Table 1. Most seedlings (74%) emerged in year 1, 21% in year 2 and 2.5% in year 3. In year 4, only 2 seedlings of contorta pine were located, and one each of Corsican, ponderosa and Scots pine and Douglas-fir. Radiata had the most rapid seedling emergence, with 98% of seedlings appearing in year 1 and none in year 3. Ponderosa pine and Douglas-fir had the most delayed emergence, with 63% and 51% respectively in year 2, followed by 4% and 7% in year 3. The only other species with appreciable delayed germination was contorta pine with 32% in year 2. The addition of fertilisers did not significantly alter the relative sequence of seedling emergence.

4. Discussion

The requirement of a Resource Consent for plantation establishment is common in the drier eastern areas of the South Island (Bowman, 2004), where much new forest planting is often on lightly vegetated and grazed rangeland where the risk of wilding spread can be high. A common condition accompanying a Consent approval is a requirement to avoid, minimise or mitigate wilding spread outside the managed area. Forest managers are therefore keen to minimise the spread risk by whatever means they can. The spreading of fertilisers to suppress seedling emergence by increasing the competition from existing cover could be an effective method.

The Mt Barker trial has shown that application of a combined nitrogen and phosphorus fertiliser to low productivity grassland can significantly depress the seedling emergence of a range of introduced conifers. The average suppression was around 42%, with contorta pine being the most suppressed species (70%) and maritime pine the least (28%). Corsican pine suppression was 35%. Davis *et al.* (1996), also working at Mt Barker, found that fertiliser addition suppressed Corsican pine seedling emergence by 56%. The difference between the two could well be explained by higher rabbit numbers at the time of the earlier trial (prior to the introduction of rabbit haemorrhagic disease). This trial was not protected from browsing, and as Davis *et al.* noted, the soil disturbance associated with the seed drilling, together with the fertiliser additions, would have made the site attractive to rabbits.

Scott *et al.* (1995) found that additions of superphosphate fertiliser on Acheron soils similar to those at Mt Barker stimulated dry matter production to four to five times that of unimproved grassland. He estimates that the addition of nitrogen could lift this to a seven-fold increase (Scott, pers com). However, these increases were on grasslands which

Table 1. Seedling emergence (% of viable seed sown) of nine conifers over 4 years.

Species	**Year 1**	**Year 2**	**Year 3** (Number of seedlings in brackets)	**Year 4** (number of seedlings in brackets)	**TOTAL** % viable seed sown (excluding Yr 4)
Pinus contorta	26.5	13.1	1.0 (6)	<.01 (2)	40.6
P. mugo	27.7	6.0	2.5 (8)	-	36.2
P. nigra	49.3	1.0	-	<.01 (1)	50.3
P. pinaster	49.2	-	-	-	49.2
P. ponderosa	16.7	32.0	2.0 (11)	<.01 (1)	50.7
P. radiata	60.8	1.3	-	-	62.1
P. sylvestris	36.7	4.4	1.1 (4)	<.01 (1)	42.2
Larix decidua	9.0	0.6	-	-	9.6
Ps. menziesii	15.1	18.3	2.4 (5)	<.01 (1)	35.8
Mean	**32.3**	**8.5**	**1.0**	**0.01**	**41.8**

had been seeded with introduced pasture species (grasses and legumes). Where there has been no such seeding (such as Mt Barker), the effect of fertilisers on dry matter production is likely to be considerably less (Scott, pers comm.). At Mt Barker, the increase in dry matter on the unimproved site was 110%. Hence, if pasture species were seeded at the same time as the fertiliser additions, dry matter production could be increased significantly and wilding numbers lowered accordingly. There is a need for further trials within grasslands susceptible to wilding invasion, to determine the effect of different rates of fertiliser, with and without the addition of pasture species. However, a possible negative effect of such increased competition could be the suppression of the native component within grasslands, as exotic grasses can suppress the establishment of native species (Ledgard and Davis, 2004). As the increased plant vigour caused by fertilising is relatively short-lived, fertilisers will need to be reapplied as long as the spread risk remains. The end result could be a long-term dominance of introduced herbaceous species, at the expense of native plant persistence. This could be a problem in areas where native species are a desired component of vegetation surrounding plantations.

The Mt Barker trial allows an estimation to be made of the cost effectiveness of using fertilisers on an unimproved grassland site. Calculations have been made for sites which are susceptible to a regular rain of conifer seed (probably close to plantations), and where the use of extensive blanket control techniques (such as burning, spraying or crushing/mulching by machine) are not an option. Therefore, removal would be by physical labour using hand tools or chainsaws. It is presumed that the fertiliser effect would last approximately 4 years (ie., repeat applications every 4 years), and that removals would be undertaken every 4 years, when wildings are between 1-2 m tall. Listed below are the inputs used for a calculation involving fertiliser to assist with the control of Douglas-fir wildings close to a mature plantation (Table 2). Urea (46% N) is used as it is currently the cheapest form for applying fertiliser nitrogen:

- Cost of physical removal of wildings 1-2 m tall - approximately $0.5 - $1/tree (contractors rates, D. Woods, pers comm.)
- Cost of applying 100 kg N / ha - approximately $500/ha (every 4 years) (Ravensdown Fertiliser Coop, pers comm)
- Effect of N application - 49% reduction in Douglas-fir wilding numbers (Mt Barker trial)

Table 2 shows that if wilding numbers are likely to exceed 2000/ha every 4 years, then the use of fertiliser at the rate of 100 kg N/ha, combined with physical removal at $0.5/wilding, could be a cost effective means of maintaining control. If the cost of physical removal rises to $1/wilding, the use of fertilisers becomes economic once wilding numbers exceed 1000/ha. As indicated above, it may be possible to reduce control costs even further if pasture species (grasses and clovers) could be seeded at the same time to significantly increase dry matter production and the competition faced by young wildings.

Contorta pine is generally acknowledged as the most vigorous spreading conifer in New Zealand (Ledgard, 2001, Ledgard and Langer, 1999). Therefore, it is a little surprising to find that it was the most suppressed species relative to seedling emergence after fertiliser application. The reason could be associated with the fact that contorta pine has the lightest seed of all the nine conifer species in the

Table 2. Break-even Douglas-fir wilding numbers for cost-effective use of urea fertiliser applied aerially at the rate of 100kgN/ha.

Wildings/ha	Fertiliser	Fert cost $/ha	Wildings/ha after fert	Removal cost/ha (@ $0.5/tree)	Total wilding control cost/ha
2000	No	NA	NA	1000	$1000
2000	Yes	$500	1020	$510	$1010

trial, and hence the smallest seed reserves to aid germination and initial establishment. If seedling suppression in the Mt Barker trial is compared to seed weight for all nine species, the correlation is negative but not significant. However, if ponderosa pine is removed, then the correlation for the remaining eight species becomes significant ($p<0.01$), meaning that the lighter the seed weight, the greater the suppression with increased competition. This is probably associated with the lower reserves in the lighter seed. Although ponderosa pine has the heaviest seed, it does not follow the same trend. The reason is unknown, but could be associated with the fact that most ponderosa seedlings emerged in the second year when the sward was more dense and competitive.

The pattern of germination over the 4 years of the Mt Barker trial can be compared to that found by Langer (pers comm.) who followed the germination of seed of seven introduced conifer species over 6 years at four sites. She found that germination was quickest on a mineral soil (nursery) site, and most delayed on vegetated sites, particularly in low rainfall areas. In the nursery, over 95% of germination was within the first year, with no germination after year 2. On the drier vegetated sites, over 95% of germination was completed by year 3, with no seedlings found by year 6. Although the Mt Barker trial has not been going as long, the indications are that seedling emergence was near completion after 3 years, with < 1% of seedlings located in year 4. In Langer's trial, delayed germination was most obvious with Douglas-fir - germination occurring in years 2 and 3, with none in year 1. The other species featuring delayed germination was contorta pine - in one of her sites (the driest) the majority of seed germinated in years 2 and 3. At Mt Barker, second-year seedling emergence was highest for ponderosa pine (63% of all emergents) followed by Douglas-fir (51%) and contorta pine (32%). Ponderosa pine had the lowest germination of all species in Langer's trial, probably due to poor seed viability.

Grazing of animals, even at light levels, can have a significant effect on wilding establishment (Benecke, 1967, Ledgard, 2006), and if stocking levels can be increased by use of fertilisers, then the suppressive effect is enhanced (Benecke, 1967). However, there are many field sites where the use of fertilisers may be an option, but where grazing is not. This may be because of location away from grazing facilities (yards, water etc), the impracticality of fencing to contain animals, or existing conservation values (such as native plants) which are incompatible with grazing. In such sites, increasing wilding suppression by the use of fertiliser alone, may well be a means of introducing more cost-effective control.

In a number of locations where introduced conifers grow well, there will always be some spread risk, requiring a commitment to the removal of wilding trees. The Mt Barker trial indicates that fertilisers could be used to increase the competition from existing vegetation and significantly lower wilding numbers, and hence physical control costs. This is likely to be most cost-effective close to plantations, where wilding density will be greatest.

5. Acknowledgements

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