Overview of the use of agri-chemicals and alternatives to control competing vegetation in forestry.

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1. INTRODUCTION

Weed control must have been one of the first cultural practices of early people as they realized that weeds interfered with food producing plants (Dangerfield and Merck, 1988). The practice of forest vegetation management has existed for close to forty years (Radosevich and Knowe, 1992). On a global scale, where plantation forestry is practised, forest vegetation management is also practised (Zedaker and Glover, 1993).

The main motivation for vegetation management in forestry is to maximise survival and growth of trees by reducing competition for limited site resources thereby realising the productive potential of the stand. Noland (1995) found reductions in diameter increment, seedling biomass, stomatal density and the number of needle primordia caused by interfering vegetation on *Pinus banksiana*, *P. strobus* and *Picea mariana*. Controlling weeds improves stand access for silvicultural and harvesting operations, fire risk is lessened by removal of forest fuel (Goodall et al., 1991; Haigh, 1987) and tree growth and harvest schedules are accelerated, resulting in greater productivity (Beneke, 1980; Nambiar and Sands, 1993; Nelson *et al*., 1981; Squire *et al*., 1987; Teeter *et al*., 1993). Forest vegetation management can be defined as the discipline of channelling limited environmental resources away from weed species to the trees, especially until canopy closure (Nambiar and Sands, 1993; Walstad and Gjerstad, 1984 ex Richardson, 1992).

Vegetation management increases timber yield by eliminating competition (Clason, 1995; Frochot et al., 1995; Richardson and West, 1993; Schumann, 1992) increasing world demand for timber (Dyck, 1995). Vegetation management practices and research are not commonly published, because companies compete to produce wood more cheaply (Donald, 1986; Perrett, 1993; Zedaker and Glover, 1993).

Vegetation management has evolved from weed control, shifting the emphasis from killing weeds to managing the tree/weed environment (McAlonan, 1993). Today the most common mechanism of managing vegetation is through the use of herbicides (Campbell, 1990; Zedaker and Glover, 1993).

Forest vegetation management also affects a wide selection of issues like, conservation, biodiversity, interactions, interactive dependence of fauna and flora, parasitism and allelopathy (Nambiar and Sands, 1993; Richardson, 1992).

Presently there are 26 registered herbicides or herbicide mixtures for use in New Zealand forestry. These herbicides are generally classified in the least hazardous “non-scheduled” category base on oral and dermal toxicity (LD50). Soil persistence of these herbicides varies considerably, but it is not excessive. Additives are widely used to enhance the efficacy of these herbicides. The increased costs associated with development and registration of new agri-chemicals, will probably mean that less new products are likely to be introduced into New Zealand. The market is so small that it is uneconomic to develop herbicides solely for forestry use

The survey conducted, indicated that herbicide inputs per unit area have decreased. Unfortunately, very few questionnaires were received back, so these results may not be representative. However, there is little doubt that in comparison to the food production sectors, forestry uses only a fraction of the agri-chemicals on a per hectare basis and their use occurs only two or three times during a 30 year rotation.

2. COMPETITION

Competition results from the crop and the weed species competing for the same limiting resources (Goldberg, 1995). Physical environmental factors affecting competition include soil water, photosynthetic active radiation (PAR), air temperature and relative humidity (Elliott and Vose, 1992).

Methods of measuring the effect of weed competition on forest trees

The following plant physiological components can be measured: net photosynthesis, transpiration, stomatal conductance, xylem pressure potential and sap flow (Elliott and Vose, 1992; Loustau et al., 1992). Foliar nutrient content, especially nitrogen, phosphate and potassium can be measured (Elliott and Vose, 1992; Lin et al., 1992). Root production, root collar diameter, needle length, tree height and groundline diameter are also commonly sampled to determine the effect of competition on tree growth (Caldwell et al., 1995; Lin et al., 1992; Oates et al., 1992).

Methods of measuring the amount of weed competition
No formalised procedure exists to assess levels of competition. Competition assessment is usually subjective and in most cases relies on experienced forest managers, who know the weeds and their ecology (Richardson, 1992).

2.1 LIMITING RESOURCES

2.1.1 Light

Light is the energy source for photosynthesis, therefore its availability and utilization are important factors affecting tree growth. High rates of photosynthesis are probably essential for high growth rates (Beneke, 1980; Minogue et al., 1991). Most pine species are shade **intolerant**, therefore they don't thrive and usually perish under low light intensities. *P. radiata* seedlings grown under overtopping vegetation assimilated less carbon dioxide and received close to 40% less photosynthetic active radiation (PAR), than unshaded seedlings (Beneke, 1980; Caldwell et al., 1995; Minogue et al., 1991). In the Southern U.S.A., *P. taeda* seedlings can only reach maximum photosynthesis under 100% sunlight, whereas woody weeds could reach maximum photosynthesis under 30% sunlight (Minogue et al., 1991).

Pinus species have thick, bundled, round needles that disperse light, and shade(s) one another. Hardwoods have broad leaves, perpendicularly orientated to the light direction, usually arranged so that mutual shading is reduced to a minimum. Vegetation management should therefore aim to minimise **shading** of pine seedlings by competing vegetation, thereby improving pine photosynthesis, to ultimately increase pine productivity (Beneke, 1980; Minogue et al., 1991). Shading trials have shown a significant reduction in biomass production if the weeds are higher than 60% of the crop tree height. In the central North Island of New Zealand, shading by herbaceous weeds is normally temporary, as weed growth declines because of moisture and temperature restrictions in the hot, dry months (Richardson, 1992).

Interspecific light competition can have beneficial effects. As canopy closure shades out light, the competing vegetation is suppressed and often eradicated. Thereafter, water and nutrient competition between trees and the understorey vegetation also declines. Usually, weeding is not necessary after canopy closure (Nambiar, 1989; Richardson, 1992). Therefore, vegetation management should be designed to accelerate initial tree growth within the first two years after planting (Gous et al., 2003; Gous, 1995). Poor early growth due to improper weed control and inadequate establishment practices (poor soil preparation, too wide espacement) will increase the time to canopy closure and extend the rotation length. This will cause a negative effect on the growth potential of a plantation (Richardson, 1992).

2.1.2 Water

The presence of weeds has been shown to reduce soil water availability to juvenile stands of *P. radiata* by increasing rates of total transpiration and wet canopy evaporation (Watt et al., 2003). Water stress in *P. radiata* causes a significant reduction in transpiration and growth (Nambiar and Zed, 1980; Squire et al., 1987). Stem, diameter and root growth are diminished by water shortage before transpiration and photosynthesis are affected (Rook et al., 1977). Nambiar and Zed (1980) found on relatively dry sites that even a 5-10% weed cover could cause enough water stress to impair *P. radiata* growth. Various studies have shown that the removal of competing vegetation, especially on dry sites, will enhance tree growth (Caldwell et al., 1995; Cellier and Stephens, 1980a; Nambiar, 1989; Nelson et al., 1981; Richardson, 1989). A variation of the water stress integral using integrated root-zone water deficit was found to be highly correlated with reductions in basal area increment of juvenile *P. radiata* growing with broom (Watt et al., 2003). Differing weed species show different rooting properties and depths, and consequently varying water usage patterns (Flinn et al., 1979). Competition for water by herbaceous weeds, with relatively shallow roots, diminished over a three year period following establishment, as *P. radiata* roots tapped water from greater depths (Richardson, 1992; Sands and Nambiar, 1984).

Plant moisture stress is a direct indication of the water availability from the soil and the demand for water from the plant. As the plant moisture stress increases, physiological processes are reduced, thereby limiting productivity until the plant dies (Sands and Nambiar, 1984; Sands and Mulligan, 1990; Squire et al., 1987). Therefore, plant moisture stress is a good indicator of the water availability and growth potential of the plant (Cleary and Zaerr).

2.1.3 Nutrients

Nambiar (1989) stated that it was difficult to in distinguish between competition for water and nutrients, because of their complex interactions. Stand volume of *P. taeda* grown in Florida increased nine times when fertiliser was applied, ten and a half times when vegetation was controlled and twenty one and a third times when weeding and fertilisation were combined (Colbert et al., 1990 ex Schumann, 1991). The above results indicate the potential interaction between fertilisation and weed control. Fertilising without vegetation control can result in increased weed growth, which induces moisture stress, resulting in tree growth reduction(s) and even mortality (Cellier and Stephens, 1980b; Flinn et al., 1979). Therefore, fertilisation should not be performed unless accompanied by weeding (Cellier and Stephens, 1980b; Nambiar, 1989; Schumann, 1991; White, 1990) in younger stands.

P. radiata, grown under weed competition, experienced a reduction in foliar nitrogen, phosphate and potassium (Sands and Nambiar, 1984). Pine growth in the southern U.S.A. is often limited by weed induced deficiencies of nitrogen and phosphorus (Minogue et al., 1991; White and Newton, 1990). Weeds directly compete for nitrogen with *P. radiata*, thereby diminishing crop growth (Richardson, 1992). Clinton and Mead, (1990 ex Richardson, 1992) found that on a dry site (East Coast of the South Island, New Zealand) four year old *P. radiata* competed with weeds for water and nitrogen. However, accompanied forest vegetation can contribute improvements to tree crops that outweigh the negative effects of competition (Richardson, 1992).

3. MAJOR WEEDS IN PINUS RADIATA PLANTATIONS

Most major forest weed species are colonising plants that initiate succession after clearfelling of mature forest plantations (Turvey, 1984 ex Richardson, 1992; Van Rossen and West, 1993). Currently the most important weed species in New Zealand plantations are:

3.1 *Buddleja davidii* (Buddleia)
3.2 *Cortaderia jubata* (Pampas)
3.3 *Cortaderia selloana* (Pampas)
3.4 *Cytisus scoparius* (Broom)
3.5 *Leycesteria formosa* (Himalayan honeysuckle)
3.6 *Pinus radiata* regeneration
3.7 *Poaceae* (Grasses)
3.8 *Pteridium aquilinum var. esculentum* (Bracken)
3.9 *Rubus fructicosus* (Blackberry)
3.10 *Ulex europaeus* (Gorse)

These weeds have emerged as the most prominent weed species since 1984 (Thompson, 1993; Richardson, 1992; Zabkiewicz, 1992 and Preest, 1985;).

4. VEGETATION MANAGEMENT METHODOLOGY

Ray and Richardson, 1995, stated that, “without good weed control it is doubtful whether commercial plantation forestry would be economically viable on many sites”. The importance of weed control has been demonstrated from the above sections. A number of weed control methods are available and they should be compared in terms of their efficacy, costs, and environmental impacts. Any potential long-term impacts must be assessed because under the Resource Management Act (1991), it is important that the forest resource is managed in a sustainable fashion.

Vegetation management should be integrated with establishment and silvicultural practices and not treated as a separate exercise (Balneaves, 1993; McAlonan, 1993; McAlonan, 1992 ex Richardson 1992). Effective chemical weeding is superior to manual weeding (Gous, 1995; Gous et al., 1992) and cover cropping (Schumann, 1991), when cost benefits and duration of control are considered. When compared to the alternative methods of controlling competing vegetation, such as crushing and burning techniques, the use of herbicides is by far more acceptable from an environmental viewpoint. Herbicides are toxic and care needs to be exercised with their use. Toxicity is expressed by the LD50 which is calculated as the dose of a chemical (mg/kg body weight) lethal to 50% of the test animals. The most commonly used herbicides in *P. radiata* plantation establishment are listed and discussed in the tables below.

4.1 Chemical vegetation management - herbicides.

In this section (I will) give an overview of the herbicides used to control competing weeds in forest establishment and silvicultural practices over a 33 year period from 1970 - 2003.

4.1.1 Chemical vegetation management – herbicidal options.

4.1.1.1 **Atrazine** is a residual triazine herbicide, absorbed by roots and foliage inhibiting photosynthesis. It is used to control annual grasses and broad-leave weeds and is often used in combination with other herbicides to control a wider range of weeds. Atrazine has a low toxicity with a half life of 35-50 days an acute oral LD50 > 3000mg/kg (rats) and acute dermal LD50 > 7500 mg/kg (rats).

From the table below it is clear that the active ingredient rate used did not change significantly. However, the application methods changed from a broadcast spray to spot application, resulting in much less atrazine used per hectare today than 30 years ago. Atrazine is not widely used today. In granular formulation it can safely be applied to *Eucalyptus nitens, E. saligna, E. botryoides and Cupressus macrocarpa*.

Trade Names: Agpro Atrazine 500 (510g a.i./l); Atradex 900WG (900g a.i./kg); Chemagro Atrazine 90DF (900g a.i./kg) Flowable Atrazine (500g a.i./l); Gesaprim 500FW (500 g a.i./l); Gesaprim 90W (900 g a.i./kg); Jolyn Atraflow 500 (500g a.i./l); Nu-Trazine 900DF (900g a.i./kg).

Atrazine

Time period	Products	Rates: kg a.i./ha	Application method	Timing	Usage	Comments
2003 – 2001	Atradex 900WG	4 –7.5	Aerial broadcast	Late Winter & Spring	Broadcast application	Gramoxone, Amitrol, Touchdown added for specific weed problems
		3.5 – 6	Spot application	Spring	Spot application, (10 - 15% of total area sprayed)	
2000-1996	Atradex 900WG, Chemagro Atrazine 90DF	4 – 6	Aerial broadcast & Knapsack	Spring	Broadcast application	
		4 – 6	Spot application	Spring	Spotgun (10 - 15% of total area sprayed)	
1995–1991	Gesaprim 500FW, Atrazine & Atradex 900WG	6 – 7.5	Aerial broadcast & Knapsack	Spring	Broadcast application	Simazine added
		4 - 9	Spotgun	Spring	Spotgun (10 - 15% of total area sprayed)	Simazine added
1990–1986	Actazine 5A & Gesaprim 500FW	4 - 8	Knapsack, Ground based, Aerial	Late winter & Early spring	Broadcast application	Dalapon or Amitrole added to widen spectrum
		4 - 8	Spotgun	Spring	Spotgun (10 - 15% of total area sprayed)	Dalapon or Amitrole added to widen spectrum
1985–1981	Actazine 5A & Gesaprim 500FW	4 - 8	Knapsack, Ground based, Aerial	Late winter & Early spring	Broadcast application	Dalapon or Amitrole added to widen spectrum
		6- 7.5	Spotgun	Spring	Spot application, (10 - 15% of total area sprayed)	Dalapon or Amitrole added to widen spectrum
1980–1976	Atrazine WP	4 -7	Knapsack, Ground based, Aerial	Spring	Broadcast application	Dalapon or Amitrole added to widen spectrum
1975–1971	Atrazine WP	4 -7	Knapsack, Ground based, Aerial	Spring	Broadcast application	Dalapon or Amitrole added to widen spectrum

4.1.1.2 **Amitrol** is a non-selective herbicide with some residual action, absorbed by roots and foliage is translocated in both the phloem and xylem, (it) inhibits chlorophyll and new bud production. Its uses include the control of Gorse, Blackberry, Californian thistle, Woolly Nightshade, grasses and herbaceous broad-leaved weeds. It was mainly used in combination with Simazine and Dalapon in the SDA formulated herbicides to increase the weed spectrum on which it was effective and also to give some residual action. Amitrol is considered as a harmful substance with an acute oral LD50 > 1100mg/kg (rats) and acute dermal LD50 > 10 000mg/kg (rats). SDA was often used to give either total long term weed control or long term selective weed control in plantations.

Amitrol was very seldomly used on its own in forestry. This product has a relatively high toxicity rating and was used at high rates to combat specific weed problems such as Blackberry and Woolly nightshade. Spot applications were mainly to control grasses. Amitrol is no longer commonly used in forest establishment practices.

Some common trade names: Amitrole 400AC (400g a.i./l), Chemagro Amitrole 40AC (400g a.i./l), Yates Amitrole 400AC (400g a.i./l). Other formulations normally include the addition of Dalapon and Simazine in mixtures, trade names are: Permazol SDA, Dowelanco SDA, Chemagro Simdole SDA and Vindex SDA.

Amitrol

Time period	Products	Rates: kg a.i./ha	Application method	Timing	Usage	Comments
2003 – 2001	No longer used extensively used for forest establishment					
2000-1996	No longer used extensively used for forest establishment					
1995–1991	Amitrole	0.4 - 0.8	Knapsack & Spotgun	Summer	Spot application to Blackberry	Follow up by burning or crushing
		10	Aerial	Pre - plant	Broadcast application for Woolly Nightshade	Retreatment may be required
1990–1986	Amitrole	0.4 - 0.8	Knapsack & Spotgun	Summer	Spot application to Blackberry	Follow up applications might be requied
1985–1981	Amitrole	10	Knapsack, Aerial, , Ground based,	Pre - plant Spring to Autumn	Broadcast application	Good coverage required
		0.4 – 0.8	Mistblower	Spring	Spot application to Blackberry	
1980–1976	Weedazol	0.4 – 0.6	Knapsack	Spring	Spot application 1.5 m x 1.5 m	Added to 10kg caragard to control grass
	Amitrole	2.0	Aerial	Late summer	Broadcast application	Grass release
		8.0	Knapsack, Ground based	Late summer to early autumn	Broadcast application	Blackberry control
1975–1971	Amitrole.	0.4 – 0.8	Knapsack, Ground based	Late winter & Early spring	Spot application	Dalapon, triazines and ammonium thiocyanate added to widen spectrum

4.1.1.3 **Glyphosate** is a non-selective, non-residual, systemic herbicide, absorbed by the foliage and rapidly translocated throughout the plant, where it primarily interferes with amino acid production. It is possibly the most successful herbicide ever produced with a very wide range of target weeds species. Glyphosate has a very low toxicity with an oral LD50 of 5600mg/kg (rabbits), a dermal LD50 >5000mg/kg (rabbits) and a half life in aerobic soils of 14 days. Glyphosate is strongly absorbed into the soil and becomes virtually immobile.

Glyphosate's use over the last 30 years has increased to possibly the most widely use herbicide in forestry for site preparation. It has replaced much more toxic herbicides such as 2,4,5,T; Paraquat and Tordon and much less acceptable slashing and burning practises for site preparation. A large number of different formulations with various surfactants are available to increase efficacy. The rate at which Glyphosate is used has decreased slightly, possibly due to improved formulations and the addition of surfactants. The most significant change however, is that the total spray application volumes have decreased from 300 l/ha to application volumes ranging from 150 l/ha to approximately 80 l/ha.

Some common trade names: Roundup, Roundup G2, Roundup Renew, Roundup Xtra, Agpro Glyphosate 450, Rodeo, Sting, Trounce, Muster, (Touchdown)

Glyphosate

Time period	Products	Rates: kg a.i./ha	Application method	Timing	Usage	Comments
2003 – 2001	Roundup Renew & Roundup G2	0.18 – 2.16	Aerial broadcast	Spring to Autumn	Broadcast application to control grasses	Add Simazine or Terbuthylazine for residual control. Pulse or Freeway added. Aerial application at 80 - 100 l/ha total spray volume
		2.16 - 3.25	Aerial broadcast	Summer to Autumn	Broadcast application for site preparation, Escort @ 100 - 200 g/ha added to increase weed spectrum	
		3.24 – 7.2	Aerial broadcast & Knapsack	Summer to Autumn	Broadcast application for blackberry and difficult to control weeds	
2000-1996	Roundup G2	0.72 – 2.16	Aerial broadcast	Spring to Autumn	Broadcast application to control grasses	Add Simazine or Terbuthylazine for residual control. Pulse or Freeway added, applied at 80 – 120 l/ha total spray volume
		2.16 - 3.25	Aerial broadcast	Summer to Autumn	Broadcast application for site preparation	
		3.24 – 7.2	Aerial broadcast & Knapsack	Summer to Autumn	Broadcast application for blackberry and difficult to control weeds	
1995–1991	Roundup & ***Touchdown***	0.72 – 2.16	Aerial broadcast	Spring to Autumn	Broadcast application to control grasses	Add Simazine or Terbuthylazine for residual control. Pulse added, applied at 150 - 200 l/ha total spray volume Add Pulse
		2.16 - 3.25	Aerial broadcast	Summer to Autumn	Broadcast application for site preparation	
		4.3 – 7.2	Aerial broadcast & Knapsack	Summer to Autumn	Broadcast application for blackberry and difficult to control weeds	
1990–1986	Roundup	1.1 – 2.16	Aerial broadcast	Spring to Autumn	Broadcast application to control grasses	Add triazines for residual control. Pulse added, applied at 150 - 200 l/ha total spray volume Add Pulse
		2.16 - 3.25	Aerial broadcast	Summer to Autumn	Broadcast application for site preparation	
		4.3 – 7.2	Aerial broadcast & Knapsack	Summer to Autumn	Broadcast application for blackberry and difficult to control weeds	
1985–1981	Roundup	1.1 – 2.2	Knapsack, Ground based, Aerial	All year	Broadcast application to control grasses	Simazine added to provide residual control
		3.5 – 4.5	Knapsack, Ground based, Aerial	Spring to Autumn	Broadcast application for bracken, buddleia, broom & blackberry control	Add Pulse
		5.4	Knapsack & Spot gun	Summer to Autumn	Broadcast application	Add Pulse
1980–1976	Roundup	1 - 2	Knapsack, Ground based, Aerial	Spring to Autumn	Broadcast application to control grasses	
		2.5 – 4	Arial	Summer & Autumn	Broadcast application for bracken control	Burn 1-2 months later
		4	Aerial	Late summer to Autumn	Broadcast application for blackberry control	Alternative to 2,4,5 - T
1975–1971	Roundup	1 - 2	Knapsack, Ground based, Aerial	Spring to Autumn	Broadcast application to control grasses	Radiata tolerant to glyphosate up to 2kg a.i./ha
		2.5 – 5	Arial	Summer & Autumn	Broadcast pre-plant site preparation	Burn 2-3 months later
		5	Aerial	Summer & Autumn	Broadcast application for bracken control	Burn 2-3 months later

4.1.1.4 **Hexazinone** is a semi - selective, residual, systemic herbicide, absorbed primarily by the roots, but also through foliage. It falls in the heterocyclic triazine herbicide group. Hexazinone is translocated throughout the plant, where it inhibits photosynthesis. It is used to control a very wide range of weeds including woody and herbaceous weed species. It is classified as a harmful substance with an intermediate toxicity. It has an acute oral LD50 of 1690mg/kg (rats) and acute dermal LD50 >5278mg/kg (rabbits). The half-life in soil is between 1 and 6 months depending on dose, soil type and climate. Therefore hexazinone can provide some soil residual weed control action to increase efficacy and the weed free period.

Hexazinone at the lower recommended rates can be used over radiata pine trees in release operations. The most common use of hexazine today, is spot release operations on hard to kill weed species. The use of hexazinone for broadcast site preparation is not widely practised any longer. The reason is mainly because there are less expensive and less toxic options available. However, in combination with terbuthylazine (Velgard & Valzine), hexazinone is one of the most widely used and successful agri - chemicals in forestry release operations to control a very broad spectrum of both woody and herbaceous weeds.

In the mid-1970's hexazinone became a popular replacement for 245-T to control hard to kill weeds. This is a very good example where a herbicide with higher toxicity (245-T) was replaced by a product with a much lower toxicity. The rates at which hexazinone is currently used per unit area is also significantly lower than when it was first used, mainly because it is used in mixtures and in spot applications, rather than broadcast sprays.

Some common trade names: Velpar 20G (200g a.i./kg), Velpar DF (900g a.i./kg), Velpar L (250g a.i./l), Velpar 90 (900g a.i./kg).

Hexazinone

Time period	Products	Rates: kg a.i./ha	Application method	Timing	Usage	Comments
2003 – 2001	Velpar DF	2.25 – 9.0	Aerial broadcast	Spring to Summer	Broadcast application for site preparation and hard to kill weeds	Use the higher rates on heavy soils and higher rainfall areas. Aerial application at 230 l/ha total spray volume. Do not add surfactant if applied over trees.
		2.25 – 4.5	Knapsack & Spotgun	Spring to summer	Release spraying over trees	
	Velpar 20G	3.0 – 6.0 6.0 – 10.0*	Spot release by Weed-A-Metre	Spring to summer	Control of broadleaf and brushweed species, high rates for hard to kill weeds*	Only 10-15% of the total area is treated,
2000-1996	Velpar DF & Velpar 20G	2.25 – 9.0	Aerial broadcast	Spring to summer	Broadcast application for site preparation and hard to kill weeds	Use the higher rates on heavy soils and higher rainfall areas. Aerial application at 230 - 400 l/ha total spray volume. Do not add surfactant if applied over trees.
		2.25 – 4.5	Knapsack & Spotgun	Spring to summer	Release spraying over trees	
	Velpar 20G & Velpar L	2.0 – 4.0 6.0 – 8.0*	Spot release by Weed-A-Metre or Knapsack	Spring to summer	Control of broadleaf and brushweed species, high rates for hard to kill weeds*	Only 10-15% of the total area is treated,
1995–1991	Velpar DF, Velpar L & Velpar 20G	5.4 – 7.2	Aerial broadcast	Spring to summer	Broadcast application for site preparation and hard to kill weeds	Use the higher rates on heavy soils and higher rainfall areas. Aerial application at 300 - 400 l/ha total spray volume. Do not add surfactant if applied over trees.
		2.0 – 4.5	Knapsack & Spotgun	Spring to summer	Release spraying over trees	
	Velpar 20G & Velpar L	2.0 – 4.0*	Spot release by Weed-A-Metre or Knapsack	Before end October	Control of grasses, broadleaf and brushweed species	Only 10-15% of the total area is treated, in spot releasing, that equates to 0.6 – 1.2kg a.i. /h
	Velpar 20G	6.0 – 8.0*	Spot treatment by Weed-A-Metre, Spotgun or Knapsack	When required	High rates for hard to kill weeds, avoid pine trees, *add surfactant	
1990–1986	Velpar DF, Velpar L & Velpar 20G	4.0 – 6.0	Broadcast, aerial and ground based	Spring to summer	Broadcast application for site preparation and hard to kill weeds	Use the higher rates on heavy soils and higher rainfall areas. Aerial application at 160 l/ha total spray volume. Do not add surfactant if applied over trees.
		2.0 – 4.5	Knapsack & Spotgun	Spring to summer	Release spraying over trees	
	Velpar 20G & Velpar L	2.0 – 4.0*	Spot release by Weed-A-Metre or Knapsack	Before end October	Control of grasses, broadleaf and brushweed species	Weed-A-Metre registered 1987. Only 10-15% of the total area is treated, in spot releasing, that equates to 0.6 – 1.2kg a.i. /h

1985–1981	Velpar 90, Velpar L & Velpar 20G	3.0 – 6.0	Aerial broadcast & Spotgun	Spring to Autumn	Broadcast application for site preparation	Can be damaging on sandy and low organic matter soils Aerial application at 300 - 400 l/ha total spray volume.
1980–1976	Velpar DF, Velpar L & Velpar 20G	4.0 – 6.0	Broadcast, aerial and ground based	Spring to summer	Broadcast application for site preparation and hard to kill weeds	Good alternative to 245-T. Provides medium to long term residual control. Risk of tree damage on light soils.
		2.0 – 5.0	Knapsack & Spotgun	Spring to summer	Release spraying over trees, to control grass and herbaceous broadleaves.	
1975–1971	DPX 3674 (Velpar)	8.0 - 16.0	Broadcast	1 day before planting radiata	Broadcast application for pre-plant site preparation	DPX 3674 registered as Velpar September 1975
		6.0 – 8.0	Knapsack & Spotgun	Spring to summer	Release spraying and pre-plant	Requires warm soil conditions

4.1.1.5 **Terbuthylazine** is a semi - selective, residual, systemic herbicide, absorbed primarily by the roots, but also through foliage. It falls in the triazine herbicide group. Terbuthylazine is translocated throughout the plant, where it primarily inhibits photosynthesis and other enzymic processes. It is used for both pre- and post-emergent control of a wide range of annual and perennial grass and broadleaf weeds in forestry, agriculture and horticulture. It is classified as a hazardous substance. It has an acute oral LD50 of 2160mg/kg (rats) and acute dermal LD50 >3000mg/kg (rabbits). Terbuthylazine is strongly adsorbed to the soil, very little leaching occurs and has a half-life in the soil between 1 and 2 months depending on dose, soil type and climate. It can provide soil residual weed control action to increase efficacy and the weed free period.

In combination with hexazinone (Velgard & Valzine), terbuthylazine is one of the most widely used and successful agri - chemicals in forestry release operations to control a very broad spectrum of both woody and herbaceous weeds. Terbuthylazine is compatible with a variety of common used herbicides, it should not be applied if rain is expected within 3 hours, it requires approximately 10mm of rain within a week to be washed into the soil. Haloxyfop, fluazifop-P-butyl are also commonly added to increase activity on grass species. Mixtures with clopyralid and hexazinone increases activity on broadleaf species. Terbuthylazine was a popular replacement for Simazine (more soluble in soil) and Amitrol (higher toxicity.

Prior to the mid 1970’s, terbuthylazine was not frequently used on it’s own. It was applied as “Caragard”, a 50/50 mixture with Terbumeton another triazine herbicide with a low LD 50 of approximately 500mg/kg (rats). Therefore this mixture was much more toxic than later mixtures which included terbuthylazine.

Some common trade names: Agpro Terbuthylazine 500 (500g a.i./l), Assett (500g a.i./l), Gardoprim 500 FW (500g a.i./l) Terb (500g a.i./l), Terbogran (900g/kg).

Terbuthylazine

Time period	Products	Rates: kg a.i./ha	Application method	Timing	Usage	Comments
2003–2001	Agpro Terbuthylazine, Terb & Gardoprim	7.5 – 10.0	Aerial broadcast	Best before Spring flush	General weed control, use higher rates if grass and gorse seedlings exceed 10cm height.	Apply in 150 – 300 l/ha total spray volume, avoid droplets smaller than 300 microns Add hexazinone for increased knockdown.
		1.25 – 1.65	Knapsack & Spot treatment	Spring to Autumn	Release spraying over trees, add selective grasskiller for hard to kill perennial grasses.	
2000-1996	Assett, Terbogran & Gardoprim	6.0 – 10	Aerial broadcast	Best before Spring flush	Annual grasses and broadleaf weeds. Used pre- and post-plant, applied over trees.	Apply in 150 – 300 l/ha total spray volume, avoid droplets smaller than 300 microns Add Amitrol or Weedazol for thistle control.
		1.65 – 2.2	Knapsack & Spot treatment	Spring to Autumn	Release spraying over trees, add selective grasskiller (Fusilade WG 1.5 – 2kg/ha) for hard to kill perennial grasses.	
1995–1991	Gardoprim 500 FW	7.5 – 10.0	Aerial broadcast	Best before Spring flush	Site preparation and release operations. Add 4 – 6 l/ha Haloxyfop to increase activity.	Apply in 150 – 300 l/ha total spray volume, avoid droplets smaller than 300 microns Add hexazinone and surfactant for increased knockdown.
		1.2 – 1.65	Knapsack & Spot treatment	Spring to Autumn	Release spraying over trees, add selective grasskiller for hard to kill perennial grasses.	
1990–1986	Gardoprim 500 FW	7.5 – 10.0	Aerial broadcast	Best before Spring flush	Site preparation and release operations. Add 4 – 6 l/ha Haloxyfop to increase activity.	Apply in 150 – 300 l/ha total spray volume, avoid droplets smaller than 300 microns Add hexazinone and surfactant for increased knockdown.
		1.2 – 1.65	Knapsack & Spot treatment	Spring to Autumn	Release spraying over trees, add selective grasskiller for hard to kill perennial grasses.	
1985–1981	Gardoprim 500 FW	6.0 – 7.50	Aerial broadcast	Winter and early Spring	Site preparation and release operations. Add 4 – 6 l/ha Haloxyfop to increase activity.	Apply in 150 – 300 l/ha total spray volume, avoid droplets smaller than 300 microns Add hexazinone and surfactant for increased knockdown.
		1.2 – 1.65	Knapsack & Spot treatment	Spring to Autumn	Release spraying over trees, add selective grasskiller for hard to kill perennial grasses.	
1980–1976	Caragard (terbuthylazine, terbumeton)	4.0 – 8.0	Broadcast aerial or ground application.	Winter and early Spring	Post-planting for selective control of grasses and annual broadleaf weeds.	These treatments tend to promote clovers. This is countered by the addition of 2,4,5 – T or Tordon 50-D
	Caragard & Paraquat	4.0 – 5.0 & 1 – 1.5	Broadcast aerial or ground application	Winter and early Spring	For pre-plant site preparation Paraquat at 1 – 1.5 kg a.i./ha was added,.	
	Caragard & Amitrol	4.0 – 5.0 & 1 – 1.5	Broadcast aerial or ground application	Winter and early Spring	Release spraying over trees, post-planting Amitrol at 1 – 1.5 kg a.i./h was added	
1975–1971	Caragard (terbuthylazine, terbumeton)	4.0 – 8.0	Broadcast aerial or ground application.	Winter and early Spring	Post-planting for selective control of grasses and annual broadleaf weeds.	These treatments tend to promote clovers. This is countered by the addition of 2,4,5 – T or Tordon 50-D
	Caragard & Paraquat	4.0 – 5.0 & 1 – 1.5	Broadcast aerial or ground application	Winter and early Spring	For pre-plant site preparation Paraquat at 1 – 1.5 kg a.i./ha was added,.	
	Caragard & Amitrol	4.0 – 5.0 & 1 – 1.5	Broadcast aerial or ground application	Winter and early Spring	Release spraying over trees, post-planting Amitrol at 1 – 1.5 kg a.i./h was added	

Picloram and **Triclopyr** have been grouped together because they were often used in combination and pre-mixed as Tordon.

4.1.1.6 **Picloram** is a selective systemic herbicide absorbed by both foliage and roots, accumulating in new growth. It has an acute oral LD50 of 8200 mg/kg (rats) and acute dermal LD50 >4000mg/kg (rabbits). It provides a soil residual action for 7 – 14 months depending on soil and climatic conditions. It falls in the pyridine herbicide group and is classified as a hazardous substance. Picloram was (a popular herbicide in mixtures) combined with Triclopyr, 2,4,5-T and 2,4-D.

4.1.1.7 **Triclopyr** is a selective systemic herbicide that is absorbed by foliage and roots with translocation through the whole plant. It induces auxin-type (plant hormone) responses as it interferes with cell division and elongation. Uses include the control of woody weeds and a large selection of broad leaved weeds. It falls in the pyridine herbicide group. It has an acute oral LD50 of 713 mg/kg (rats) and acute dermal LD50 >2000mg/kg (rabbits). Triclopyr has a half-life of 46 days depending on soil and climatic conditions. It is classified as a hazardous substance.

These products (Grazon and Tordon Brushkiller) are often used at low rates (1.0 – 2.0 l/ha) in aerial release operations against seedling gorse in young radiata stands. It is also a very economical spot release product with a relatively low toxicity used at very low rates. As a stump treatment against a variety of woody weeds (Hawthorn, Old Man's Beard, Sweet Brier, Woolly Nightshade, etc.), applied at 1 part herbicide in 20 parts water or diesel.

Some common trade names: Garlon (600g a.i./l); Garlon 520 (193g a.i./l triclopyr+ 100g picloram a.i./l), Renovate (300g a.i./l), Renovate Gorsekiller (300g a.i./l); Grazon (600g a.i./l); Brush Off (600g a.i./l); Scrubcutter (600g a.i./l) and Victory (600g a.i./l), Tordon Brushkiller (300g a.i./l triclopyr + 100g picloram a.i./l), Tordon 2G (20g a.i./kg);).

Picloram and **Triclopyr**

Time period	Products	Rates: kg a.i./ha	Application method	Timing	Usage	Comments
2003 – 2001	Grazon, Renovate, Brush off	0.9 - 9.0	Aerial broadcast in 200l water/ha	Spring to Summer	Broadcast application for site preparation and hard to kill weeds	Effective against Blackberry, Gorse, Broom and Himalayan honeysuckle. Use lower rate if trees are not dormant.
		.0.6 – 1.2	Aerial broadcast in 100 – 200 litres water/ha	Spring	Release spray against seedling broom & gorse.	
		0.6 – 1.8	Spotgun application @ 1000 – 2000 kPa	Spring to Summer	Avoid direct contact with trees if spot releasing. Add organosilicone @ 100ml/100l.	Rates calculated on 500 l/ha total volume application, as per spotgun.
	Tordon Brushkiller	10 l/ha product	Aerial broadcast	Spring	Broadcast application for site preparation and hard to kill weeds	Adding Boost Penetrant is recommended.
		3.0 – 10.0 l/ha product	Aerial broadcast	Spring to Summer	Release spray against seedling broom & gorse.	
2000-1996	Grazon, Renovate, Brush off	0.9 - 9.0	Aerial broadcast in 200l water/ha	Spring to Summer	Broadcast application for site preparation and hard to kill weeds	Effective against Blackberry. High rates used on hard to kill natives and Blackberry.
		.0.6 – 1.2	Aerial broadcast in 100 – 200 litres water/ha	Spring	Release spray against seedling broom & gorse.	
		0.3 – 0.9	Knapsack & Spotgun	Spring to Summer	Avoid direct contact with trees if spot releasing.	
	Tordon Brushkiller	10 l/ha product	Aerial broadcast	Spring	Broadcast application for site preparation and hard to kill weeds	
		3.0 – 10.0 l/ha product	Aerial broadcast	Spring to Summer	Release spray against seedling broom & gorse.	
1995–1991	Grazon	0.9 - 9.0	Aerial broadcast	Spring to Summer	Broadcast application for site preparation and hard to kill weeds	Effective against Blackberry. High rates used on hard to kill natives and Blackberry.
	Tordon Brushkiller	10 l/ha product	Aerial broadcast	Spring to Summer	For pre-burn desiccation.	
	Grazon	0.3 – 0.9	Knapsack & Spotgun	Spring to Summer	Avoid direct contact with trees if spot releasing.	Only 10-15% of the total area is treated, in spot releasing

1990–1986	Grazon	0.9 - 9.0	Aerial broadcast	Spring to Summer	Broadcast application for site preparation and hard to kill weeds	Effective against Blackberry. High rates used on hard to kill natives and Blackberry.
	Tordon Brushkiller	10 l/ha product	Aerial broadcast	Spring to Summer	For pre-burn desiccation.	
	Grazon	0.3 – 0.9	Knapsack & Spotgun	Spring to summer	Avoid direct contact with trees if spot releasing.	Only 10-15% of the total area is treated, in spot releasing
1985–1981	Garlon 520	4.0 – 5.0 l/ha product	Broadcast, aerial ground based and knapsack	Spring to Autumn	Broadcast application for pre-plant site preparation, frequently followed by a prescribed burn.	An effective product against Blackberry, gorse, broom and Himalayan honeysuckle. Only available in mixture with Picloram.
1980–1976	Garlon 520	1.0 - 4.0 l/ha product	Broadcast, aerial ground based and knapsack	Spring to Autumn	Broadcast application for pre-plant site preparation	A broad spectrum hormone alternative to 2,4,5 – T. Often used as a pre-burn treatment. Only available in mixture with Picloram.
1975–1971	Grazon	1.0 - 4.0	Aerial, ground based, spot gun and mistblower	Spring to Autumn	Broadcast application for pre-plant site preparation	A broad spectrum hormone alternative to 2,4,5 – T.

Hormone Weedkillers: 2,4 D & 2,4,5,T and MCPA (These herbicides are effective against broad leaved species but not grasses.)

4.1.1.8 **2,4 D** (2,4-dichlorophenoxy acetic acid) is a selective systemic herbicide absorbed by both foliage and roots. Translocation occurs through the whole plant with accumulation principally at the meristematic regions of the roots and shoots. It induces auxin-type (plant hormone) responses and acts as a growth inhibitor.

Used to control annual and perennial broad-leaved weeds. It falls in the phenoxy herbicide group. It has an acute oral LD50 of 375 mg/kg (rats) and acute dermal LD50 >1600mg/kg (rabbits). 2,4 D can remain residual in the soil for 6 weeks depending on soil and climatic conditions. It is classified as a hazardous substance.

4.1.1.9 **2,4,5,T** (2,4,5-trichlorophenoxy acetic acid) was one of the main components of Agent Orange, which received disrepute after it was extensively used as a component in the defoliant in the Vietnam war (Agent Orange). It is closely related to a number of other herbicides, such as 2,4-D (2,4-dichlorophenoxyacetic acid) and MCPA (2-methyl-4-chlorophenoxyacetic acid), which are plant growth stimulants which cannot be metabolised by plants. Therefore if they are applied in high concentrations they cause lethal, uncontrollable and grossly distorted growth. 2,4-D and MCPA were the first hormone herbicides and the first really selective weed killers, which killed weeds but did not harm other plants or animals. 2,4,5,T has an acute oral LD50 of 500 mg/kg (rats) and acute dermal LD50 >5000mg/kg (rats). 2,4 D can remain residual in the soil for 6 weeks depending on soil and climatic conditions. It is classified as a hazardous substance.

Agent Orange (never used in New Zealand forestry)

Combined with 2,4-D, this spray was named Agent Orange. 2,4,5-T is extremely effective as a defoliant, and has even been used in the UK to control brambles encroaching on footpaths or railway lines by the Forestry Commission and British Rail, respectively. It has great advantages in that is has low toxicity to animals and is cheap to manufacture. It is the second step in the reaction that has caused all the problems, since the temperature has to be carefully controlled. If it rises above 160°C a side-reaction between two of the sodium intermediates occurs producing the deadly tetrachlorodioxin. It is claimed that the products used in New Zealand had no or very low levels of dioxin.

Although the 2,4,5-T molecule itself was non-toxic, the small quantities of the dioxin impurities caused many problems. These included a greater incidence than normal of malformed babies in villages close to zones that had been sprayed with Agent Orange. The US National Cancer Institute established that the dioxin, which was present in 2,4,5-T at concentrations of only 10-30 ppm, was responsible for producing malformations in mammalian babies.

1970 – 1975 spray volumes were, 450 l/ha by knapsack and 150 l/ha by mistblower.

Some common **2.4.-D** trade names: Weedar 77 TD (400g a.i./l **2.4. – D**); IWD Hi-ester (720g a.i./l **2.4. – D**); IWD 2.4.-D amine (400g a.i./l **2.4. – D**);
Some common **2.4.5.-T** trade names: IWD Hi-ester (720g a.i./l 2.4.5. – T); Broadside (600g a.i./l 2.4.5. – T); Weedone (360g a.i./l 245-T); Weedone Hi-ester (720g a.i./l 245-T); Winstone's double strength (720g a.i./l 245-T)
Some common **mixture** trade names: Scrub Desiccant TD (400g a.i./l 2.4. – D & 400g a.i./l 2.4.5 . – T); Banvel D (400g a.i./l 2.4. – D & 75g a.i./l dicamba); Tordon 50-D (200g a.i./l 2.4. – D + 50g picloram a.i./l); Tordon Brushkiller DS (400g a.i./l 2.4.5 . – T + 100g picloram a.i./l)

Hormone Weedkillers: 2,4 D & 2,4,5,T

<table>
<tr><th>Time period</th><th>Products</th><th>Rates:
kg a.i./ha</th><th>Application method</th><th>Timing</th><th>Usage</th><th>Comments</th></tr>
<tr><td>2003 – 2001</td><td colspan="6">No longer in regular use for forest establishment or release operations.</td></tr>
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<tr><td>1990–1986</td><td colspan="6">No longer in regular use for forest establishment or release operations.</td></tr>
<tr><td rowspan="9">1985–1981</td><td>IWD Hi-ester 2.4. – D</td><td>4.0 – 8.0</td><td>Broadcast aerial application</td><td>Winter to early Spring</td><td>Used for pre-burn desiccation and site preparation.</td><td>Commonly used together with 2.4.5.-T</td></tr>
<tr><td>IWD 2.4.-D amine</td><td>1.0 – 1.5</td><td>Knapsack and ground based vehicle</td><td>Winter to early Spring</td><td>Selective tree release of radiata pine and Douglas fir.</td><td>Avoid spraying active growth.</td></tr>
<tr><td>IWD Hi-ester 2.4.5. – T, Broadside</td><td>4.0 – 8.0</td><td>Broadcast aerial application</td><td>Winter to early Spring</td><td>Used for pre-burn desiccation and site preparation.</td><td>Commonly used together with 2.4.-D, or Picloram. Surfactant or diesel added to increase efficacy.</td></tr>
<tr><td>IWD Hi-ester 2.4.5. – T, Broadside</td><td>1.0 – 1.5</td><td>Knapsack and ground based vehicle</td><td>Spring to early summer</td><td>Selective tree release of radiata pine and Douglas fir.</td><td>Broadside preferred, avoid spraying active growth</td></tr>
<tr><td>Banvel D</td><td>4.2 – 6.3 l/ha product</td><td>Knapsack and ground based vehicle</td><td>Late Autumn to early Winter</td><td>Site preparation, mainly used to control herbaceous broadleaves.</td><td>Unsuitable for release operations.</td></tr>
<tr><td>Tordon 50-D</td><td>4.0 – 5.0 l/ha product</td><td>Broadcast, ground or aerial.</td><td>Spring to Autumn</td><td>Site preparation, mainly used to control herbaceous broadleaves</td><td>Unsuitable for release operations.</td></tr>
<tr><td>Scrub Desiccant</td><td>6.0 – 20 l/ha product</td><td>Aerial or ground based broadcast application</td><td>Late Spring to early summer</td><td>Site preparation, clearing of indigenous and exotic broadleaf scrubweeds, including broom and gorse.</td><td>Often used together with a prescribed fire.</td></tr>
<tr><td rowspan="2">Tordon Brushkiller DS</td><td>5.0 – 10.0 l/ha product</td><td>Aerial or ground based broadcast application</td><td>Late Spring to early summer</td><td>Controls most exotic and indigenous scrubweeds.</td><td>Addition of diesel increases efficacy.</td></tr>
<tr><td>1.0 – 2.0 l/ha product</td><td>Knapsack and ground based vehicle</td><td>Late Spring to early summer</td><td>Controls scrubweeds and thistles.</td><td>Severe distortion damage can occur if trees are sprayed.</td></tr>
</table>

1980–1976	2.4. – D Esters	4.0 – 8.0	Broadcast application	Late Spring to early summer	Used for non- selective broadleaf scrub weed control	Selective on dormant Douglas fir at 1-2 kg/ha
	2.4.5. - T Esters	4.0 – 8.0	Broadcast application	Spring to Autumn	Non-selective control and pre-burn desiccation at high rates.	Formulations containing picloram, dicamba or 2.4. – D and tank mixes with 2.4. –D or diquat are commonly used for this purpose.
		1.0 – 2.0	Aerial broadcast application	Spring to early summer	Selective control of scrub weeds in Radiata pine and Douglas fir at low rates.	
	Scrub Desiccant TD	5.0 – 10.0 l/ha product	Broadcast application	Spring to Autumn	Pre-burn scrub desiccation including gorse and broom.	Extensively used for woody weed control. Diesel added to increase knockdown.
	Tordon Brushkiller DS	5.0 – 10.0 l/ha product	Aerial or ground based broadcast application	Late Spring to early summer	Pre-plant site preparation or pre-burn desiccation of scrub weeds.	Addition of diesel increases efficacy.
		1.0 – 2.0 l/ha product	Aerial broadcast application	Late Spring to early summer	Release spraying of Radiata pine should be done within the first year after planting to avoid tree damage.	Distortion damage can occur if trees are sprayed. Used to control gorse, broom, Himalayan honeysuckle, blackberry, thistles, etc.
1975–1971	Scrub Desiccant TD	10 l/ha product	Broadcast application	Late Spring to early summer	Used for **Gorse** control. Followed by a burn 10 – 14 weeks post application..	400g/l 2.4. – D + 400g/l 2.4.5. – T. Better gorse rootstock control was achieved when Picloram was added at 50g/l.
	Weedar 77 TD	22 kg/ha	Broadcast application	Spring to Autumn	Used to spray nursery surrounds.	
	Weedone 245-T	2.0 kg/ha	Broadcast application	Spring and summer	Broadcast application for radiata release, post plant, 2nd rotation.	Extensively used for woody weed control.
	Weedone 245-T, Weedone 245-T Hi-ester	8.0 – 12 kg/ha	Aerial broadcast application	Late Spring to early summer	Site preparation, mainly used to control broadleaf native herbaceous and woody weeds.	Applied in 225l – 450l /ha, diesel added at 11.0 – 22.0 l/ha. In some cases **sodium chlorate** was added at up to 45kg/ha to increase efficacy and weed spectrum.
	Scrub Desiccant TD	8.0 – 12 kg/ha	Aerial broadcast application	Late Spring to early summer	Site preparation, clearing of natural forest.	Paraquat at 2.8 l/ha added together with diesel at 11 to 22 l/ha.

Diquat and Paraquat (Bipyridylium herbicides)

Both **Diquat** (Reglone) and **Paraquat** (Gramoxone) are non-selective contact herbicides, absorbed by the foliage, with some translocation in the xylem. During photosynthesis, superoxide is generated, which damages cell membranes and cytoplasm. These herbicides are active on green photosynthesising tissue. They produce a rapid brown-out and desiccation, but generally fail to kill plants with extensive root systems. For best results a good coverage is required. Used for the control of broadleaved weeds, compatible with many other herbicides.

These products are classified as poisonous. Persons with lung problems may be at increased risk from exposure. Many cases of illness and/or death have been reported in humans. The estimated lethal dose (via ingestion) for paraquat in humans is 35 mg/kg. A maximum of 3.5 mg/hour could be absorbed through the dermal or respiratory route without damage.

4.1.1.10 **Diquat** has a an acute oral LD50 of 230 mg/kg (rats) and an acute dermal LD50 >750 mg/kg (rabbits), which makes it one of the most toxic herbicides.

4.1.1.11 **Paraquat** is highly toxic via ingestion, with an acute oral LD50 of 150 mg/kg (rats) and an acute dermal LD50 250 –500 mg/kg (rabbits).

Some common Diquat trade names: Reglone (200g a.i./l Diquat), Midstream (200g a.i./l Diquat), Reglex (200g a.i./l Diquat).

Some common Paraquat trade names: Preeglone (125g a.i./l Paraquat), Gramoxone(200g a.i./l Paraquat

Diquat and Paraquat

Time period	Products	Rates: kg a.i./ha	Application method	Timing	Usage	Comments
2003 – 2001	These products are no longer in regular use for forest establishment or release operations. ***any operations?***					
2000-1996	These products are no longer in regular use for forest establishment or release operations.					
1995–1991	These products are no longer in regular use for forest establishment or release operations.					
1995–1991	These products are no longer in regular use for forest establishment or release operations.					
1990–1986	These products were no longer in regular use for forest establishment or release operations. However, it was still used in isolated cases to control ***Pinus contorta*** as a pre-burn desiccant.					
1985–1981	Reglone (diquat)	1.0 – 2.0	Broadcast, aerial and ground based	Spring to summer	Mainly broadleaf weed control.	Often used in combination with 2.4. – D & 2.4.5. – T. Both chemicals are potentially very toxic to humans and must be handled with extreme care.
	Gramoxone (paraquat)	1.0 – 2.0	Broadcast, aerial and ground based	Spring to summer	Mainly broadleaf weed control., but in combination with Simazine commonly used for pre-plant grass control.	
1980–1976	Reglone (diquat)	1.0 – 2.0	Broadcast, aerial and ground based	Spring to summer	Mainly broadleaf weed control.	Used in mixture with 2.4. – D & 2.4.5. – T for pre-burn scrub weed desiccation and on gorse in the autumn and early winter. Both chemicals are potentially very toxic to humans and must be handled with extreme care.
	Gramoxone (paraquat)	0.5 – 2.0	Broadcast, aerial and ground based	Spring to summer	Mainly broadleaf weed control., but in combination with Simazine commonly used for pre-plant grass control.	
1975–1971	Diquat	3.0 – 3.5	Broadcast	Spring to summer	Broadcast application for pre-plant and pre-burn site preparation.	Used with hormone weed killers (2.4. –D and 2.4.5. – T) as a pre-burn desiccant.
	Gramoxone (paraquat)	0.5 – 3.20	Broadcast, aerial and ground based	Spring to summer	Mainly broadleaf weed control., but in combination with Simazine commonly used for pre-plant grass control.	

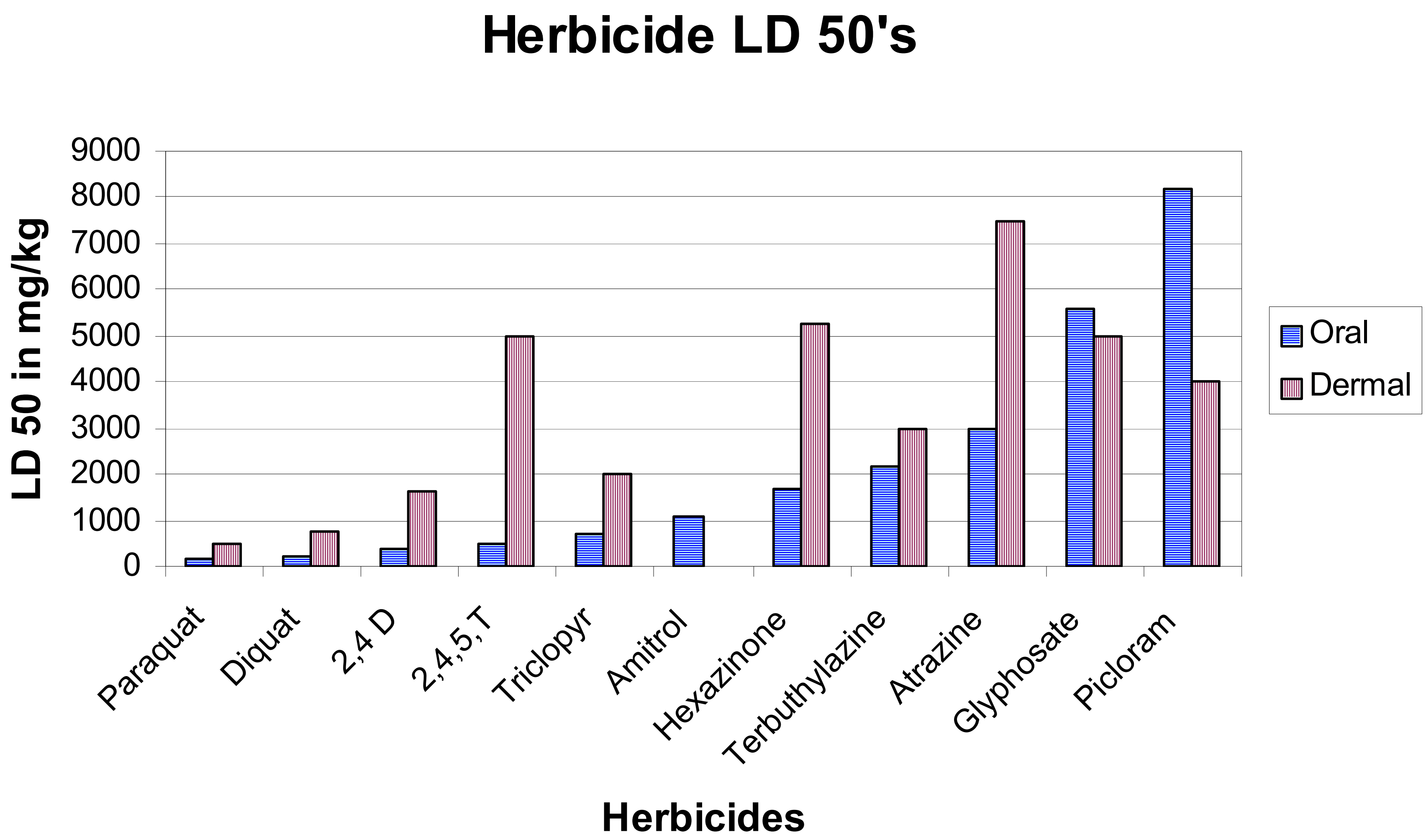

Figure 1. Herbicide LD 50's ranked from low to high (low LD 50 = high toxicity).

The following case study (table 1) typically indicates how pre-plant site preparation has changed over the last 33 years. Fire (together with herbicides) was the main tool used for site preparation prior to the 1970's. During the next 10 – 15 years high rates of relatively high toxicity (compared to today) herbicides were used, fire became less important. From the mid-1980's less toxic herbicides became available. The total application volumes were also reduced significantly from 200 – 250 l/ha to 80 l/ha.

Table 1. Historical record of pre-plant site preparation in Kinleith Forest, Central North Island.

Time period	Products	Rates: (Product)	Application method	No. Treatments	Spray volume	Area
2000-1996	Roundup or Trounce added to	5.25 – 8.25 l/ha 4.0 – 5.0 kg/ha	Aerial – Helicopter	1	80 l/ha	29000
	Escort	100 – 250 g/ha				
1995–1991	Roundup or Trounce added to	5.25 – 8.25 l/ha 4.0 – 5.0 kg/ha	Aerial – Helicopter	1	80 l/ha	19000
	Escort	100 – 250 g/ha				
1990–1986	Roundup added to	6.0 – 9.0 l/ha	Aerial – Helicopter	1	80 – 160 l/ha	15500
	Escort	100 – 300 g/ha				
1985–1981	Gramoxone	2.0 l/ha	Aerial – Helicopter	1	100 – 200 l/ha	14200
	Tordon Brushkiller DS	5.0 – 10.0 l/ha				
	Scrub Desiccant (	6.0 – 20 l/ha				
1980–1976	Gramoxone	2.0 l/ha	Aerial – Helicopter and Fixed Wing	1	100 – 200 l/ha	10000
	Tordon Brushkiller DS	5.0 – 10.0 l/ha				
	Scrub Desiccant (	6.0 – 20 l/ha				
1975–1971	Weedone 245-T	2.0 l/ha	Aerial – Fixed Wing	1	200 – 250 l/ha	15000
	Weedar 77 TD (2.4. – D)	22 kg/ha				
	Soda Kill	6.0 – 20 l/ha				
1970–1966	**Slash and burn, often roller crushed for first rotation radiata pine establishment**					
1965–1961	**Slash and burn, often roller crushed for first rotation radiata pine establishment**					

This study has been compiled with the assistance of CHH (Paul Stevens & Gordon Beets). This data comes from historical site preparation records of the Kinleith forest central North Island

4.1.1.12 Summary

Figure 1 shows the LD 50's of the most commonly used herbicides in New Zealand Forestry. From this graph and the two tables below, it is very clear that the forest industry today are using herbicides and chemicals with far lower toxicity levels than 30 years ago. Vegetation management practices have also changed considerably, as can be seen in Table 1.

Prior to the 1970's herbicides were not commonly used for site preparation. Manual and mechanical weed control was used in conjunction with prescribed fire. These practices used very small amounts of chemicals, but the environmental consequences were considered far less desirable than using environmentally acceptable herbicides to control unwanted vegetation.

From the early 1970's until the late 1970's, site preparation still often involved a pre-plant spray followed by a prescribed burn. The most frequently used herbicides were: 245-T ester, diquat, picloram, paraquat, dalapon, dicamba, aminotriazole, karbutilate, Tordon 75T and SDA mixtures. These herbicides (with relatively high toxic rates) were applied at high rates and diesel was frequently used to enhance the performance of herbicides.

The most common weeds that had to be controlled were gorse, bracken and broom. A prescription to kill gorse was a broadcast herbicide application using from 11 to 23 l/ha, 245-T/picloram mix plus 2.8 l/ha diquat plus 27 l/ha diesel in 450 – 550 l/ha water (Davenhill 1975).

This method still resulted in significant re-growth. For broom "eradication", 17 l/ha 245-T/picloram in 220 l/ha water was recommended, but results was variable. Davenhill reported that it was difficult to wet broom and suggested that an appropriate sticker should be used to increase wetability. He recommended to apply 245-T/picloram at a dilution of 1:200 at 6500 l/ha total volume spray applied by high pressure hose (which equates to about 32.5 l/ha 245-T/picloram) to achieve good results. In 1975 (FRI symposium No. 18) it was stated that the methods of application and equipment associated in applying herbicides, definitely needed improvement.

Aerial application was normally done by fixed wing aircraft applying high spray volumes (200 l/ha – 350 l/ha).

During the next 10 years, 1980 – 1990, many changes occurred (in combating competing vegetation). The most significant was that new herbicides became available replacing some of the more toxic products in use up to that time. Typically the hormone herbicides was phased out and replaced by especially the triazine type herbicides as well as glyphosate. Fire was also less often used to clear sites before planting commenced. These practices were much more environmentally friendly and more acceptable.

Aerial application became more refined and rotary wing aircraft became more affordable and more frequently used. Spray volumes were still relatively high and very little literature was available suggesting that adjuvants were used to enhance herbicide efficacy.

Since the early 1980's to date, not many new herbicides have been registered for use in forestry. The emphasis therefor shifted towards using the available products at lower rates and to improve efficacy by the addition of adjuvants. Research during this period focused strongly on improving application techniques. Spot release became more important and became widely practised as an alternative to blanket spraying. New Zealand became one of the leaders in forestry vegetation management during this period.

There is a much greater knowledge of the products available and far more care and precision is taken to improve application techniques. Adjuvants have replaced the use of petrochemicals to enhance pesticide efficacy.

A great number of contractors and operators, applying pesticides in forestry, today are certified Growsafe pesticide applicators. Although this is not a legal requirement, the forest industry have been pro-active to ensure that the products are used by trained people that have a far greater understanding of the pesticides they use and their potential risk, than what was the case before.

The New Zealand Site Management Co-operative and private forest companies have invested a lot of time and money over the past decade to improve pesticide application techniques and to better understand the way competing vegetation reacts with the trees.

Forest Research developed two software decision support systems i.e. Vegetation Manager (VMAN) and Spray Safe Manager (SSM) I and II in collaboration with the U.S.D.A.

VMAN assists the user in deciding on which treatment should be used to control competing vegetation. Spray Safe Manager accurately calculates aerial spray deposition and is used most frequently in pre-spray analysis.

From the above it is very clear that the forest industry is constantly seeking to improve vegetation management practices, ranging from using environmentally more acceptable products, reducing herbicide rates, to improving application techniques. For this purpose, dose response trials are currently conducted to minimise to use of herbicides and gain maximum weed suppression to ensure maximum crop growth.

Table 2. Some commonly used agri-chemicals in New Zealand forestry.

Agrichemical	Aquatic	Mammalian	Plant
24-D	High	Low	High
24-D & picloram	High	Very Low	High
Bacillus thuringiensis	Very Low	Low	Low
Chlorpyrifos	High	Medium	Low
Clopyralid	Low	Very Low	High
Deltamethrin	High	Low	Low
Diazinon	Medium	Medium	Low
Glufosinate - ammonium	Very Low	Low	High
Glyphosate	Medium	Very Low	High
Haloxyfop	High	Low	High
Hexazinone	Very Low	Low	High
mcpa	Low	Low	High
mcpa + mecoprop + dicamba	Low	Very Low	High
Metsulfuron	Medium	Very Low	High
Paraquat	Medium	Low	High
Picloram granules	Medium	Very Low	High
Propiconazole + fenpropimorph	High	Very Low	Low
Simazine	Medium	Very Low	High
Tau - fluvalinate	High	Very Low	Low
Trichlopyr	Low	Low	High
Copper salts	High	Very Low	Low
	Toxicity rating	**LD50 mg/kg**	
Criteria	Very Low	>2000	
	Low	300-2000	
	Medium	10-100	
	high	<10	

4.1.2 Application methods

4.1.2.1 Handheld applicators

Liquid herbicide applicators are classified by the volume of mixture applied per hectare. Lyle (1981) describes three categories, i.e. high volume sprayers (200 – 300 l/ha), low volume sprayers (normally motorized, 30 - 100 l/ha) and ultra-low volume sprayers (less than 10 l/ha). Most handheld applicators use low release heights and are less prone to off-target drift making it environmentally a safer option. Spot herbicide release by handheld applicators is more economical and environmentally more acceptable than other application methods, because a smaller area is treated and less herbicide is used. Spot herbicide release costs depend on the number of stems per hectare. For 1500, 1000 and 600 stems/ha the cost is approximately 14%, 10% and 6% respectively of a total broadcast herbicide application. A number of spot applicators are available such as a spot gun (liquid application) and the "Weed-a-metre" (granular application) (Davenhill et al., 1995; Davenhill et al., 1989; Richardson et al., 1995; Zabkiewicz, 1989). The application of granular herbicides are simple compared to liquid herbicides. Granular herbicides require no mixing (as they are applied without water) and no calibration (applicator delivers a measured quantity of product) of application equipment. Accurate, fast, quick, easy application is therefore possible (Stewart, 1993).

4.1.2.2 Ground base applicators

In the southern U.S.A. and Canada ground machinery is favoured to treat sensitive areas, where aerial application is not advisable. Application equipment may be mounted on farm tractors, skidders, four wheel drive off-road vehicles and track-driven tractors. Three basic designs are found: spreaders, ground sprayers and mistblowers. Spreaders apply solid or granular herbicides, usually by rotating disk, or by air pressure driven blowers. Swath width varies from 1.5m to 28m. Ground sprayers apply water-diluted herbicides normally through a boom and nozzles to the inter-row. Mistblowers apply water-diluted herbicides, by releasing spray through nozzles in front of high-speed fans, which blow the spray mist onto the target area. Mistblowers are not commonly used in forestry due to fine herbicide vapour and subsequent drift risk (Desrochers and Dunnigan, 1991; Minogue et al., 1991; Richardson, 1992; Zedaker and Glover, 1993)

4.1.2.3 Aerial applicators

This method of herbicide application is fast, economical with very high accuracy and uniform application patterns. It is desirable especially over dense, restrictive vegetation, in remote areas, on steep slopes and where large areas are to be treated (Minogue et al., 1991; Perrett, 1993; Turvey, 1984). Sixty seven percent of the herbicides applied in Canada in 1988, were done by aircraft (Campbell, 1990). Fixed-wing aircraft or helicopters may be used for application of liquid or granular herbicides. In New Zealand helicopters are preferred over fixed-wing aircraft because forestry areas are relatively remote, making "turn-around" time (taxi time to and from airstrips, to land refuel and refill with herbicides), long and expensive.

Helicopters can land on site to refuel and fill-up with herbicide, they are more suited to treat small irregular shaped areas, they can fly slower causing less shearing of droplets, causing less drift; they follow contours better for even application and are more accurate over steep broken terrain (McDonald, and Fiddler, 1989; Minogue et al., 1991; Ray et al., 1993).

In New Zealand, herbicide efficacy and productivity were improved, from 22ha/hr to 38ha/hr, by reducing aerial applied spray volume from 160 l/ha to 80 l/ha (Jones, 1995). Ray et al. (1993) concluded that a reduction in aerial spray volumes to 50 l/ha, increased active ingredient (a.i.) recovery and reduced application costs.

The United States Department of Agriculture (USDA) Forest Service developed a computer aerial spray model, known as the FSCBG (Forest Service Cramer-Barry-Grim) model. In collaboration with the U.S.D.A., Forest Research in New Zealand has developed Spray Safe Manager, based on the FSCBG model. This software uses modern G.I.S. technology to predict the behaviour (deposition and dispersion) of spray material, through nozzles into the wake of the spray craft, as a function of atomisation, weather and application parameters. These programs provides tools to obtain off-target deposition data without conducting extensive and expensive field-testing (Barry, 1985; Barry and Teske, 1993; Teske et al., 1993).

4.2 Alternatives to chemical vegetation management – non herbicidal options

4.2.1 Abiotic

4.2.1.1 Overview

At present chemical vegetation management is the preferred method to control weeds in New Zealand forestry. However, alternative non-chemical management options have not been ignored and neglected. Before herbicides became widely available late in the 1960's, fire and manual / mechanical weed control were the only options available. These methods are very well documented in the past in the FRI Symposia (1, 22, 23). These alternative methods of vegetation management have virtually been phased out since the introduction of cost-effective herbicides and more stringent environmental regulations.

From early on it was apparent that no weed control was untenable. Successful plantation establishment depends on seedling survival and low mortality at establishment. If no weed control was undertaken, *P. radiata* mortality would be high and growth loss is inevitable. In recent times much more competitive weed species, such as buddleia, broom and pampas, have invaded the forests which means that it is highly unlikely that no weed control will ever be an option. It would be possible to utilise low light tolerant species such as Douglas fir, as they could survive with much more light competition. However, growth would most likely be retarded, but this may not be so significant over the longer rotation period, as later growth could catch up during the rotation.

Currently cultivation methods in relation to chemical weed control have also declined. The main reasons is the high cost of using machinery and working in difficult terrain, which make it less attractive. Gravity roller crushing is a possible exception, where the withdrawal of subsidies for chemicals meant that it became more cost-competitive with herbicides.

More recently, techniques such as over-sowing with grasses and legumes, combined with grazing by cattle have become cost effective weed management options in some areas. The main restrictions are that over-sowing can lead to more frost damage, and animal control and management skills are required.

Biological control is specific, as control agents need to be identified and established for each weed species. The forestry weeds that have had biocontrol agents introduced are gorse, broom, buddleia and clematis.

4.2.1.2 Mechanical weed management

Tractor-mounted mowers, brush-cutters and chopper-rollers are the equipment most commonly used for mechanical weeding (Hall, 1993; Minogue et al., 1991; Richardson, 1992). Care has to be taken that soil compaction by this equipment does not cause greater growth reductions than the benefits to tree growth by controlling the vegetation. Hand held brush-cutters can be used for mechanical weeding, but these machines pose a high risk to operator safety (Thomas et al., 1988 ex Minogue, 1991).

Mechanical weed management cannot be practised where slopes are too steep, tree espacements are too small, or where soils are unstable and easily erodible. Physical obstructions such as large rocks, large stumps and debris from harvesting can severely hamper mechanical weeding. In New Zealand and Australia respectively, only 3% and 10% of the annual vegetation management is done mechanically (Boomsma and Hunter, 1990; Minogue et al., 1991). In South Africa, mechanical vegetation management is seldom done in *P. radiata* stands.

Soil cultivation, as part of site preparation, improves the physical condition of the soil. These operations create a degree of mechanical vegetation management, as weeds are removed by ploughs, discs and rippers (Mason et al., 1988 ex Richardson, 1992). However, one-way soil cultivation does not control weeds in the tree row (Minogue et al., 1991). Site type dictates the methods that are used. Spot cultivation can be very intensive (up to 40%) in frost flat regions.

4.2.1.3 Manual

Labour costs normally dictate the extent of how much manual weeding can be afforded (Balneaves, 1981; Donald and Kirby-Smith, 1982). Manual weeding has a low environmental impact and has been in use since the early 1920's. It is still practised today mainly to control pine wildlings. Hoeing, hand pulling and slashing were the most frequently used methods of vegetation management in *P. radiata* plantations in South Africa up to the early 1980's (Donald, 1986). Balneaves (1981) reported that manual vegetation control in Australia and New Zealand is only used as a last resort, because of its high costs. Therefore, spot release from weeds, by handheld applicators, are preferred above total area spray, because less labour is required than for total area sprays. The advantages are that it requires no chemical inputs but it is ineffective to control invasive weeds, it has a relatively short duration and frequently requires repeat treatments.

4.2.1.4 Fire

The main advantages of fire as a vegetation management tool is that a clean burn removes unwanted vegetation, (including pine wildings, pine cones and seed) and debris after harvesting. Re-establishment of the plantation is therefore easier and cheaper. A fire can kill or stimulate weed seed germination, after which the seedlings can be controlled chemically (Balneaves et al., 1992 ex Richardson, 1992). Prescribed fires remove forest fuel and thereby reduce the risk of wildfires (Martin et al., 1979). In New Zealand with its higher rainfall, fire was used more frequently than in Australia, the southern U.S.A. and South Africa, where the fire risk was higher (Boomsma and Hunter, 1990; Minogue et al., 1991). Fire is a relatively inexpensive vegetation management operation compared to other vegetation management options (Minogue et al., 1991).

The disadvantages of fire as a vegetation management instrument are the loss of nutrients, weed invasion and soil erosion due to fast water run off. Other problems are the risk off the fire "escaping" into neighbouring plantations, negative public opinion and possible environmental damage (Hall, 1993; Minogue et al., 1991; Richardson, 1992). Environmentally, fire as a weed control option is no longer acceptable above most chemical vegetation control options.

4.2.1.5 Oversowing / intercropping

The logic of oversowing is to establish a cover crop so that the crop trees and cover crops are mutually supportive rather than competing with one another. Cover crops should be a more easily manageable vegetation cover than the original weed cover. Nitrogen fixing cover crops have increased in popularity because of increased crop tree productivity, simple rotations, ease of control, reduction of soil erosion and contribution to weed control. In the Central North Island oversowing has increased from 6% in 1991, 29% in 1992 to 45% in 1993 (Nambiar and Sands, 1993; Schumann, 1991; Van Rossen and West, 1993). Oversowing has been in use since the early 1980's. However, currently (2003) its use as a means of vegetation management is on the decline again. Oversowing is often done by fixed wing aircraft. Seeds are sown similarly to aerial fertiliser application (Geddes, 1993).

Cover crops compete for water, light and nutrients. Therefore cover cropping, especially with perennials, is not recommended where resources, such as available water, become limiting. Cover crops should be removed before tree growth is impaired (Eccles and Little, 1995). Intercropping *P.radiata* with annual lupins, which die in the dry summer, showed increased tree growth and soil nitrogen reserves (Nambiar and Sands, 1993). In some cases oversowing does not inhibit weed growth sufficiently, so spot herbicide treatment is then used for tree release (Eccles and Little, 1995; Zabkiewicz, 1992). Oversowing cannot be used extensively throughout NZ forest areas due to frost problems.

4.2.2 Biotic

4.2.2.1 Grazing

Animals used for grazing include cattle, sheep, goats and pigs. Grazing can be a very effective and lucrative vegetation control option, but requires additional farming skills not always possessed by foresters. It can be practised in compartments with low initial stocking (Pearson, 1981 ex Minogue, 1992). Grazing should start before weed dominance occurs and when trees are one to two years old. It can be very beneficial in pampas grass infested areas. Silvicultural concerns with grazing include soil compaction, soil disturbance and damage to trees. Suitable live stock must be found that will utilize the weed vegetation in preference to crop trees. Therefore, the weed vegetation must be palatable in preference to crop trees. Water must be available to the animals and additional fencing will be required. The initial costs to start such an operation are high. All forest sites are not suitable for grazing either (Balneaves and McCord, 1990 ex Richardson, 1992; Minogue et al., 1991; Richardson, 1992). Richardson (1992) reported that successful grazing has been implemented in both Australia and New Zealand. Due to the potential physical damage to the trees, grazing as a vegetation control option is not always possible before age 3, so it is not such a good weed control option.

4.2.2.2 Biocontrol – insects

Potentially biological control of weeds, mainly by insects, is very attractive. Unfortunately, there is a long lag time after the introduction period until reasonable control is achieved, mainly due to slow insect population build up. Biocontrol has the potential to reduce pest plant infestations in the very long term. To date the Gorse weevil has been the most significant insect biocontrol agent, but it requires continuous areas of gorse to be effective. Forest Research is currently conducting research into the control of Buddleia by *Cleopus japonicus*). The insects feed externally on the leaves of buddleia. The laboratory results suggest that *C. japonicus* feeding could cause significant reduction in survival of buddleia seedlings in the field, and reduced competition with radiata pine seedlings, but these results still need to be confirmed by the results of mechanical damage in the field.

4.2.2.3 Mycoherbicides

Mycoherbicides can be defined as naturally occurring fungal pathogens that have been developed to control weeds. Currently no effective mycoherbicides are available for use in forestry. This form of weed control is inexpensive compared to chemical herbicides. They are as a rule host specific, making them selective to the target weeds only. Mycoherbicides can be used in conjunction with chemical herbicides. Extreme care must be taken that the crop species are totally resistant to pathogens selected for use as herbicides (Ayres and Paul, 1990).

5. CROP RESPONSE TO VEGETATION MANAGEMENT

Weed control resulted in Gous (1995) in a 40% increase in both height and diameter growth of two year old *P. radiata*. Herbaceous weed control, irrespective of duration (one or two years) or method (inter-row or total area), increased height of *P. taeda* at age nine years (Lauer et al., 1993). Similarly, Quicke (1995) found dbh, basal area and volume increases where herbaceous vegetation was controlled for two years in *P. taeda* stands. Brown (1989) stated that no tree crop would exist without weed control. Most weed control treatments during the first two years resulted in at least a 25% increase in volume at age nine (Lauer et al., 1993). Various studies have shown growth gains from vegetation management, e.g. *Abies balsamea* produced a 64% volume increase, when released from herbaceous weeds (MacLean and Morgan, 1983 ex Richardson, 1989). *Pseudotsuga menziesii* showed a 260-405% basal area increase ten years after treatment (Radosevich et al., 1976 ex Richardson 1989). Butcher (1980) found a sixteen percent volume loss *of P. pinaster* through competing vegetation. From the above data it is clear that considerable crop growth gains can be expected from vegetation management.

Economics

Limited data are available on the long-term effects of vegetation control on the growth of radiata. Such data are important to quantify economic thresholds for weed control treatments (Balneaves and Christie, 1988; Busby, 1988; Cain, 1991). To make a return on investment from forestry, expected earnings from capital expenditure, especially early in the rotation, must result at least in sufficient timber increase to break even with the costs (De Laborde, 1991). Generally, the costs of controlling woody weeds are higher than the costs of controlling herbaceous weeds (Dangerfied and Merck, 1988). Spot release from competing vegetation can result in an economic gain, because only a small percentage (depending on initial stocking) of the total plantation area is treated (Zabkiewicz, 1989). In first-world countries, vegetation management practices centre around chemical options, as high labour costs and low labour availability makes this option less feasible (Zedaker and Glover,1993).

6. RESEARCH NEEDS/FUTURE DEVELOPMENTS

Plantation establishment or vegetation management decision-support-systems software such as VMAN could become a pivotal tool in optimising vegetation management in New Zealand. For that purpose it is important to extend the current research to include as many weeds and herbicides as possible. The New Zealand Forest Site Management Co-operative is currently investing large resources in further dose response trials to constantly improve VMAN. These models capture the experience of many experts resulting in very powerful decision-support systems (Mason, 1993; Mason, 1995).

The forest industry will have to seek to minimise the use of agri-chemicals to successfully establish and re-establish plantations. Therefore it will become more important to understand the biology of the weeds and how best to control it. Competition models for light, water and nutrients should be integrated to optimise early growth of the crop trees.

During the last decade significant progress have been made with adjuvant research. These products enhance herbicide efficacy and can potentially further reduce herbicide rates by improving uptake due to better spreading and forced uptake into the target species.

Future research with herbicides will have to address the following topics: environmental destiny, refinement of rates, optimisation of spot size and duration treatments, improvement of application methods, weed crop interactions, human health risk and economic viability of herbicide treatments (Gjerstad et al., 1993; Richardson et al., 1995; Versteeg, 1992).

Genetic engineering of *P. radiata* to make it resistant to specific herbicides is currently underway (Walter et al., 1995), however this might meet with strong opposition from environmentalists. More work on other forestry crop species is needed. Minimal-disturbance site preparation with reduced herbicide rates should be further investigated (New, 1993).

7. CONCLUSIONS

A consistent increase in the global use of pesticides is predicted, despite intensive efforts to introduce biological and integrated pest control practices (Food and Agriculture Organization, 1990). In 1989, Zabkiewicz predicted that herbicides would continue to be an essential tool for vegetation control, although not the only one.

Today almost 15 years later, there are still very few alternatives available that can compete with herbicides based on economics, efficacy and environmental impact. Therefore, chemical vegetation management should be practised to cause as little detrimental impact on the environment as possible to ensure that forestry can be practised in a sustainable fashion.

Weed management should be designed to accelerate tree growth. Therefore, weeds should be controlled, particularly early in the rotation, as this is the time when the most significant growth gains are made (Gous et al., 2003, Wagner et al., 1995). Weed control has the effect of shifting the growth curve back along the time axis. Therefore, in plantations with weed control, reduced rotation lengths can produce the same volume of timber than the same unweeded plantation, if severe mortality does not occur (Richardson, 1989; Schumann, 1991). From literature it is clear that chemical forest vegetation management resulted in improved tree growth and survival, with considerable economic earnings, with no long lasting detrimental environmental impact.

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