CHEMICAL CONTROL OF *POA TRIVIALIS*
ON
NEW ZEALAND RACETRACKS

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ABSTRACT

Poa trivialis is a perennial grass weed commonly found in perennial ryegrass (*Lolium perenne*) racetrack swards throughout New Zealand. Its presence is undesirable as it does not tolerate high wear and is susceptible to dying out over the summer. Two pot trials at Massey University and one field trial carried out at the Awapuni racecourse were conducted during winter and spring 1995 to test the relative susceptibility of *Poa trivialis* and perennial ryegrass to a wide range of herbicides. A bioassay was also conducted to determine whether herbicide residues from the field trial could affect the germination of perennial ryegrass seed sown soon after treatment. Results showed that none of the chemicals at their chosen respective rates could completely remove *Poa trivialis* from a racetrack sward in the spring without some damage been caused to perennial ryegrass. Propyzamide and fenoxaprop at rates of 0.2 and 0.15 kg/ha respectively showed the most potential of the chemicals, severely damaging *Poa trivialis* (causing 50 to 75% reductions) with no adverse effect on perennial ryegrass 8 weeks after spraying. Propyzamide can also provide some control of *Poa annua*. Fenoxaprop was not improved by increasing the application rate or adding an oil. The performance of fenoxaprop was substantially reduced when applied with either MCPA or a picloram/triclopyr mix. Dalapon and asulam showed good potential to control *Poa trivialis* but at the high rates tested caused variable or harmful effects to perennial ryegrass. Ethofumesate and chlorpropham applied at rates of 2.0 and 2.5 kg/ha respectively gave inadequate control of *Poa trivialis*. None of the above herbicides, when used in the field trial, resulted in residues which reduced the germination of perennial ryegrass seed sown 3 weeks after spraying. Herbicides tested in the pot trials which showed poor control of *Poa trivialis* were atrazine, dicamba, isoproturon/diflufenican, linuron, mecoprop, methabenzthiazuron, metsulfuron, pendimethalin, prometryne, thifensulfuron-methyl, triclopyr, and trinexapac-ethyl. Diuron applied at 2.6 kg/ha provided good control of *Poa trivialis* but caused significant damage to perennial ryegrass. It is concluded that an integrated management approach that incorporates both cultural and chemical techniques will be required to control *Poa trivialis* on New Zealand racetracks. Future trial work should be carried out on propyzamide applied at rates of 0.2-0.3 kg/ha in autumn to establish the most appropriate time of year to apply this herbicide.

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1. INTRODUCTION

Poa trivialis, commonly known as rough stalked meadow grass, is a perennial grass weed frequently found in racetracks throughout New Zealand (Field & Murphy 1987). Its presence is undesirable as it does not tolerate high wear and is susceptible to dying back over summer. For high quality racing surfaces in New Zealand, it would be preferable if tracks were composed of 100% perennial ryegrass (*Lolium perenne*) (Fleming 1994). A shift in sward composition away from *Poa trivialis* can be aided dramatically by cultural control techniques. Attention to drainage, aeration, fertiliser treatments, sensible location of rails and fences, regular under-sowing and irrigation may all discourage *Poa trivialis* in a perennial ryegrass sward (Fleming 1994). However, in many situations, due to adverse climatic or edaphic conditions *Poa trivialis* can still form a significant proportion of the sward. As cultural methods alone seldom reduce populations of *Poa trivialis* to an acceptable level there is a need for direct chemical elimination of *Poa trivialis* from racetrack swards. Also for ease of management, it would be preferable if this weed could be removed from the racetracks using a herbicide.

It has proved relatively easy to find a chemical which will control *Poa trivialis* (Kirkham 1983; Mueller-Warrant & Brewster 1986). However, many effective treatments cause phytotoxicity to perennial ryegrass in the sward (Henderson & Brock 1976; Mueller-Warrant 1990; Jensen 1984).

Use has been made of ethofumesate (Nortron), though this is an expensive option ($440/ha) and not thought very effective at killing *Poa trivialis* (Harrington 1994). Other herbicides may be more effective, but such options need to be investigated with well-designed pot and field trials.

The objective of this research was to determine which chemicals, if any, can be used to effectively remove *Poa trivialis* from racetracks with minimal damage to perennial ryegrass.

2. LITERATURE REVIEW

2.1 Roughstalked meadow grass (Poa trivialis)

Information on the biology has been fully reviewed elsewhere (Vartha 1969; Fleming 1994). Therefore a further complete review of literature pertaining to this species is not appropriate. However, some relevant aspects are discussed below as an overview to the project.

2.2 Importance in New Zealand

Poa trivialis is a native of northern Europe. In New Zealand, the accepted common name for this species is rough-stalked meadow grass (Healy 1984) although it is also called rough meadow grass.

Poa trivialis was introduced to New Zealand to improve lowland grassland pastures. Inclusion of *Poa trivialis* in early pasture mixtures was desirable as this species provided a dense cover in the bottom of pasture, limiting ingress of weeds that would otherwise have colonise spaces where the sown species did not persist (Vartha 1969). Improvement in persistence of perennial ryegrass through breeding superseded this role of *Poa trivialis* in pasture. According to Vartha (1969) it has probably not been sown since the initial establishment of most pastures.

In New Zealand perennial ryegrass has been the predominant grass species used on racetracks (Field & Murphy 1987). It is one of the most tolerant turf grasses to heavy wear (Beard 1973). Where undersowing occurs it is generally done with this species. Yet results from a survey of ten race tracks in the North Island of New Zealand, shows that only half the tracks are ryegrass dominant and a number have a very little ryegrass (Field & Murphy 1987).

Unlike perennial ryegrass, *Poa trivialis* does not form a tight vigorous sod with the soil. The grass species may be easily dislodged from the soil surface by galloping horses and is also very susceptible to dying out over the summer due to having a very shallow root system. According to Field & Murphy (1987), *Poa trivialis* will suffer more damage and incur higher repair cost than perennial ryegrass growing on the same soil type.

In conclusion a reduction of *Poa trivialis* and an increase in perennial ryegrass sward content on any race track will result in an improved racing surface. Management changes that produce a perennial ryegrass dominant sward will result in reduced repair cost and safer horse racing overall.

2.3 Biology of Poa trivialis

2.3.1 Morphology

Poa trivialis is a perennial grass of prostrate growth habit with slender creeping stolons. Distinguishing features, as listed by Lambrechtsen (1992) are:

Upper leaf surface	:	Yellowish to bright green, without ribs, but distinct 'tram-lines' and pointed tip.
Lower leaf surface	:	Very glossy.
Emerging leaf	:	Folded.
Sheath	:	Usually rough, rarely smooth; often has purplish or brownish tinge.
Ligule	:	In young tillers 1-2 mm long; membranous; slightly pointed; translucent to whitish. In older tillers 2-10 mm long; membranous; distinctly pointed; whitish.
Auricles	:	Absent

Poa trivialis may best distinguished from the other *Poa* species commonly found in New Zealand, (ie *Poa annua* and *Poa pratensis*) by being stoloniferous, having rough sheaths, very shiny lower leaf surface and longer pointed ligules.

A further description of the plant vegetative parts is given by Lambrechtsen (1992) and the floral parts is given in Hubbard (1984).

Figure 2.1: Diagram of the *Poa trivialis* plant

Source: Hubbard (1984)

2.3.2 Seed production and germination

Poa trivialis is primarily propagated from seed but can also spread by vegetative reproduction ie stolons. Seed production is prolific estimated at 1500 seeds per head (Budd and Shildrick 1968). Work on the seed biology by Budd (1970a) shows that *Poa trivialis* plants need to be vernalised by exposure to winter conditions in order to produce seed the following year.

Seed dispersal on a racetrack is likely to be by wind, birds or equipment as the seed readily adheres to mowers (Fleming 1994). According to Budd & Evans (1972) shed seed of *Poa trivialis* shows no dormancy and will germinate on the soil surface when suitable conditions occur. Once incorporated into the soil surface by foot traffic (*i.e.* horses' hooves), viable seed can survive in a dormant state for up to two years (Budd & Evans 1972).

Seed germination of *Poa trivialis* is promoted by red light (670 nm) and reduced when exposed to far red-light (720 nm) (Hilton *et al* 1984). Most authorities agree that *Poa trivialis* seed can germinate under shade conditions (Beard 1973; Hurley *et al* 1990). This was confirmed by Collingwood and Frost (1988) who found that *Poa trivialis* was beneficial in camp and caravan site seed mixes, due to the ability of the grass to germinate and survive under opaque ground covers for a long period of time.

Poa trivialis is considered amongst the hardiest of cool season turf grasses. Whyte, Moire, and Cooper (1959) suggested *Poa trivialis* requires a minimum temperature of 5 °C for seed germination. The optimum temperature for *Poa trivialis* seed to germinate is 20 °C (Froud-Williams, 1985). While the main flush of germination usually occurs in autumn, additional germination may take place during periods of mild weather throughout the winter and spring (Oswald 1980).

2.3.3 Vegetative reproduction

Poa trivialis vegetative reproduction consists of stolons that are secondary lateral shoots which arise above ground, with considerable horizontal stem elongation and grow indeterminately at the soil surface when exposed to light. The plant may develop new shoots and root quite readily from stolon nodes (Beard 1973). This vegetative structure of *Poa trivialis* makes the racetrack environment an ideal habitat for invasion and spread of plants due to the track surface being continually opened up by horses' hooves, allowing for ease of spread of new stolon growth.

2.4 Reaction to environmental stress

For clarity, each major environmental factor is considered individually. However, *Poa trivialis* does not respond to only one environmental factor but to the combined effect of many factors. For example, the influence of light on *Poa trivialis* growth and development varies with temperature (Vartha, 1969). Inter-relationships among various factors are ever changing.

2.4.1 Light

A general comparison of the competitive ability of turf grass seedlings for light by Beard (1973) found *Poa trivialis* of average ability. Italian ryegrass (*Lolium multiflorum*), perennial ryegrass, tall fescue (*Festuca arundinacea*) and meadow fescue (*Festuca pratensis*) all rate as more competitive for light. The order of species competition was positively correlated with the germination rate, seedling vigour, and vertical leaf extension rate. These three factors cause increased shading and attrition of less vigorous species. The use of these grass cultivars with superior seedling growth planted at high seeding rates would reduce the probability of *Poa trivialis* establishing in the turf grass sward.

2.4.2 Temperature stress

Whyte, Moire and Cooper (1959) suggested *Poa trivialis* grows best at soil temperatures of 15 to 24 ^{0}C and, as the temperature increases or decreases from the optimum various metabolic processes with in the plant are slowed. Beard (1973) lists the symptoms of heat stress as a progressive stolon browning and die back, followed by a reduction in shoot growth and finally darkening of the leaves and death. Death of the plant may be caused by other factors such as high temperature stress that is likely to occur at the time of most intensive use of the turf.

As temperatures decrease below the optimum there is a point at which growth ceases. Beard (1973) states shoot growth in *Poa trivialis* is suppressed by constant soil temperatures of 5 to 10 °C . Soil temperature is more critical than the air temperature. Respiration and photosynthesis continue at a slow rate below 10 °C and may be still take place close to 0 ^{0}C, but if the temperature continues to decrease death occurs. Tolerance of cool season grasses to low temperatures varies, with *Poa trivialis* considered amongst the hardiest (Beard 1973).

2.4.3 Moisture stress

Beard (1973) states *Poa trivialis* has a higher wilting tendency and poorer overall drought resistance than most other common turf grasses. On racetracks where soil is compacted by treading there is a progressive loss of cover. Such areas are frequently colonised by *Poa trivialis,* but due to the compacted nature of the soil and the shallow root system the plant only survives while surface moisture exists. Over summer months *Poa trivialis* may die or completely stop growing, when exposed to an extended period of heat and moisture stress. It has the ability under more favourable growing conditions, ie autumn, to initiate new growth from the stolons. This cessation of leaf tissue growth due to heat and moisture stress is sometimes termed summer dormancy (Schmidt, 1970). For this reason, the grass species is commonly used in the USA as a dormant grass over-seeded on Bermudagrass (*Cynodon dactylon*), because it quickly establishes providing a satisfactory turf quality during the winter allows easy transition stage back to the *Cynodon* species in the summer (Edminister 1994).

Poa trivialis thrives in moist conditions and is one of the few grasses relatively well adapted to survive in water logged soil conditions (Field & Murphy 1991). In winter on many race tracks in New Zealand these conditions exist due to poor drainage or heavy soils underlying the track surface. These conditions provide a competitive environmental edge for *Poa trivialis* over other cool season grasses such as perennial ryegrass.

2.4.4 Wear tolerance

Considerable variation in wear tolerance is exhibited at different stages of growth and among turf grass species (Beard 1973). Young seedlings are much less wear tolerant than mature turf grasses. A vigorous actively growing turf has better wear tolerance than a weakened or dormant turf (Wrigley 1991). The warm season turf grasses are generally more wear tolerant than cool season species (Table 2.1). More wear tolerant cool season grasses such as perennial ryegrass possess a tougher coarse stem and leaf structure, higher shoot density and lignin content. In contrast less tolerant grass species, such as *Poa trivialis,* have a soft succulent type of growth (Shearmen & Beard 1975). In a race track environment it is important to have turf grass species that have good wear characteristics to allow the safe execution of the horses hoof through the three phases of contact with the turf, ie deceleration, support and propulsion, otherwise injury may occur.

Table 2.1: The relative wear tolerance of twelve turf grasses when grown in their respective regions of adaptation.

Relative Wear Tolerance	Turfgrass Species
Excellent	Zoysiagrass (*Zoysia minima*) Bermudagrass (*Cynodon dactylon*)
Good	Tall fescue (*Festuca arundinacea*)
Medium	Perennial ryegrass (*Lolium perenne*) Kentucky bluegrass (*Poa pratensis*) Meadow fescue (*Festuca pratensis*) Canada bluegrass (*Poa compressa*) Red fescue(*Festuca rubra*)
Poor	Creeping bentgrass (*Agrostis stolonifera*) Redtop (*Agrostis gigantea*) Browntop (*Agrostis capillaris*)
Very poor	***Poa trivialis***

Source: Beard (1973)

2.4.5 Nutritional requirements

A statistical study of racetrack data by Field & Murphy (1987) indirectly established that *Poa trivialis* on tracks was positively associated with high levels of available soil phosphorous (P). Ryegrass cover was not associated with soil P or soil potassium (K), but did appear to be linked to K fertiliser applications. Highest quantities of perennial ryegrass were found where K fertiliser was applied. This is in accordance with the modern perception in turf management that K is important for stress resistance and persistence of desirable species (Adams & Gibbs 1994).

According to Edminister (1994), *Poa trivialis* prefers moderately fertile soils with best growth occurring between pH 6 and 7. Under high alkaline soils (pH greater than 7.5), *Poa trivialis* appears to have a good tolerance to low soil iron levels and will not exhibit yellowing chlorosis unless under extremely high pH (Edminister 1994).

2.4.6 Summary

Poa trivialis is a long-lived perennial adapted to grow throughout cool, humid temperate climates of the world. It grows best in shade, cool, moist, moderately fertile environments. Low temperature hardiness and ability to withstand water logged conditions make the soil conditions of New Zealand racetracks an ideal environment in which to grow through the winter. However, the plant is intolerant of wear and droughty soils and under these conditions that are prevalent in summer months of racing *Poa trivialis* may enter temporary dormancy or die.

2.5 Cultural control of *Poa trivialis*

Cultural control is a protective or preventative method of control. It involves manipulation of the environment to encourage desirable species and reduce undesirable species. Techniques for the reduction of *Poa trivialis* have been discussed in detail by Fleming (1994) and findings are summarised below.

2.5.1 Prevent or reduce compaction.

Excess moisture and traffic induced compaction results in shallow rooting conditions that favour *Poa trivialis* dominance in a turf grass sward. The traffic effects will be reduced by using appropriately designed machinery, ie light weight mowers, turf type tyres, and movable running rails. Remedial measures such as verti-draining or vibra-moling, dependent upon soil type, will reduce or relieve compaction. Good soil structure provides better drainage and penetration of water and air encouraging better root growth and competition by desired grass species (ie perennial ryegrass) on the racetrack.

2.5.2 Select suitable turf grass species and cultivars.

In the racetrack environment a turf grass plant experiences considerable stress due to the traffic effect. It is important to select a grass species that has good wear characteristics. Perennial ryegrass is most commonly sown on race tracks in New Zealand as it has a good deep root system that is quick to establish and can survive well in cool wet soil environments. Despite advances in breeding dwarf cultivars of perennial ryegrass these more expensive releases have been little used on racetracks in New Zealand. The potential exist to improve turf quality of racetracks using dwarf cultivars as they can provide a more wear resistant, compact dense turf, if correctly managed.

Since the 1980's a considerable amount of research has been carried out into grass species for wear characteristics suitable for the racetrack environment. Kentucky bluegrass and tall fescue species have shown many desirable attributes for a racetrack sward in cool season climates *ie* ability to maintain high soil strength in wet conditions. As yet no race track in New Zealand has used either grass species as the main component of the turf grass sward. Potential for using these species is likely to be localised rather than general in New Zealand.

2.5.3 Mow at correct height.

Poa trivialis tends to dominate in turf situations that are not mown frequently, preferring less defoliation than perennial ryegrass. Increasing intensity and frequency of mowing discourages *Poa trivialis*. Maximum height of cut should be approximately 60 to 80 mm to discourage *Poa trivialis*. Certain practical considerations are necessary when establishing the cutting height. Winter racing usually incurs substantial surface disruption. Mowing too close (less than 60mm) will tend to mulch the lifted clods and destroy existing plant material. Summer racing results in less surface disruption due to a firmer surface and plants not being held as loosely in the soil. Mowing height under such conditions can be reduced to 60 mm.

2.5.4 Avoid excessive phosphate levels.

A reduced phosphate fertiliser application is a key to reducing *Poa trivialis* content in a perennial ryegrass turf sward. Increased levels of phosphate have been positively associated with high levels of *Poa trivialis, Poa annua* and white clover (*Trifolium repens*) in a ryegrass pasture sward. The placement of phosphate fertiliser on the soil surface gives *Poa* species and white clover an advantage over perennial ryegrass due these species having a shallow root system. Thus, a reduction in phosphate fertiliser application or placement below the soil surface is required when carrying out renovation.

2.5.5 Avoid shallow watering.

Shallow watering fails to promote deep root growth and has been positively associated with high levels of shallow rooting grass species ie *Poa trivialis* on racetracks. Where possible infrequent deep watering must remain a priority. Irrigation should be based upon the desirable grass species needs and the desirability of maintaining a soil profile with consistent moisture characteristics to depth.

2.5.6 Removal of thatch

Thatch is the accumulation of decaying, fibrous debris that sprawls across or is deposited upon the racetrack surface from grass shoots and clippings. Thatch impedes drainage encouraging shallow rooting grass species such as *Poa trivialis* to grow well in the environment. Regular remedial work with a mechanical dethatcher is required to remove high levels of thatch from a race track sward.

2.5.7 Summary

Cultural control techniques are available for reducing *Poa trivialis* which do not make use of herbicides. But in many situations, due perhaps to adverse climatic conditions or poor construction, *Poa trivialis* may still form a significant proportion of the sward. Thus as cultural methods alone seldom reduce populations of *Poa trivialis* to an acceptable level, there is a need for direct chemical elimination of *Poa trivialis* from racetrack sward. Also, for ease of management, it would be preferable if this weed could simply be removed from the racetracks using a herbicide.

2.6 *Chemical control of Poa trivialis*

In racetracks, the control of broad-leaved weeds is not difficult to achieve using broad-spectrum herbicides. The good tolerance of perennial ryegrass to herbicide mixtures and the lack of amenity shrubs next to most parts of racetracks makes control of broad-leaved species easier than in many other turf situations (Harrington 1994). However, grass weeds are more difficult to remove with herbicides. Physiological and morphological similarities between desirable and undesirable grass species mean few selective herbicides are available for removing grass weeds. Success of any herbicide chosen for control of *Poa trivialis* on racetracks will depend on efficacy against this species and tolerance to perennial ryegrass.

The following summarises trial work on herbicide utilised in *Poa trivialis* and perennial ryegrass swards and information on all herbicides selected for trial work. Most research on herbicide selectivity in *Poa trivialis* and perennial ryegrass has been done on seed crops and pastures.

2.6.1 Ethofumesate

Ethofumesate that is marketed in New Zealand under the trade name Nortron. (O'Connor 1994). Although it may be taken up from the soil it is primarily taken in through the shoots of grass species and roots of broad-leaved weeds. Grasses often fail to emerge from the coleoptile and broadleaved species only develop to the cotyledon leaf stage. At sub lethal rates, foliage becomes darker green and an effect on surface wax is accompanied by leaf trapping and subsequently deformity (Roberts 1982).

Ethofumesate controls *Poa annua* in perennial ryegrass seed crops (Ball & Roberts 1974). Cannaway & Peel (1985) also showed this where various combinations of pre and post emergence treatments at different application timings were evaluated for control of *Poa annua* in a perennial ryegrass sward, subjected to football type wear and renovated by overseeding. In this study the most effective program consisted of three post emergence treatments of ethofumesate at 2 kg/ha at approximately monthly intervals beginning in late spring. In New Zealand ethofumesate has been used to selectively control *Poa annua* in perennial ryegrass swards in several situations including sports fields, cricket wickets, golf green surrounds and golf tees. Cumulative applications similar to those evaluated under UK conditions have been used here (Glasgow 1991).

Caution is required with the use of ethofumesate in race tracks consisting of grasses other than perennial ryegrass. In the USA, high doses of ethofumesate have caused phytotoxicity to Kentucky bluegrass (Dernoeden & Turner 1988). In New Zealand, McLean (1978) discovered appreciable phytotoxicity to desirable turf grass species using ethofumesate in fine turf situations. Wrigley (1991) examined the effect of ethofumesate on shoot and root growth of three turf grass species: 'Bardot' browntop (*Agrostis capillaris*) 'Dawson' fescue (*Festuca rubra*) and 'Penncross' creeping bent (*Agrostis stolonifera*) the chemical significantly reduced leaf and shoot weights of all three turf grass species at rates of 0.5 kg/ha and above. Therefore, it appears wise to use ethofumesate on turf comprising of ryegrass only. According to Hare & Rolston (1990) ethofumesate is damaging to white clover at 1-1.5 kg/ha. This is advantageous on a racetrack as white clover produces a slippery surface when covering hard ground.

Research on the effect of ethofumesate on *Poa trivialis* has been minimal, compared with *Poa annua*. Partial control of *Poa trivialis* has been reported for ethofumesate in the UK but economically questionable rates of 2.0 kg/ha or higher are required. Mead *et al* (1974) observed good control of *Poa trivialis* (rate of 2 kg/ha) through the winter in the UK in a perennial ryegrass seed crop. Coats & Krans (1986) in the USA found that ethofumesate applied pre-emergence at 1.1 kg/ha controlled *Poa trivialis* and *Agrostis species* in turf without significantly affecting ryegrass cultivars. Post-emergence application rates of 1.1, 2.2, and 4.4 kg/ha of ethofumesate all significantly reduced shoot dry weights of *Poa trivialis* compared with the untreated control. However, Hammond *et al* (1976) and Mueller-Warrant and Brewster (1986) found post-emergence applications of ethofumesate gave variable control of *Poa trivialis* in perennial ryegrass seed crops. This variable control may have been caused by poor timing of applications or adverse edaphic conditions. Haggar and Bastian (1976) in the UK found that the activity of ethofumesate was reduced if the soil had high organic matter levels or was dry for a long period of time.

2.6.2 Carbamates

The herbicidal activity of the carbamates was discovered in 1945 with the introduction of propham. Since then many more carbamates have been developed. The basis of selectivity between tolerant and sensitive species is believed to be due to differential rates of degradation. Two carbamates used selectively for grasses are chlorpropham and asulam. Both are systemic herbicides that exert their main effect by inhibiting the process of cell division in the growing points of the plant (Roberts 1982). Greatest visual effect of the treatments occurs in new growth of the plant.

Chlorpropham is approved for control of annual weeds in certain vegetable crops and marketed in New Zealand under the trade name Chloro IPC (O'Connor 1994). The herbicide may enter the plant through the emerging shoot of a germinating seedling and through foliage and roots of older plants. Mueller-Warrant and Brewster (1986) found chlorpropham applied pre-emergent at 2.2 kg/ha provided only fair control of *Poa trivialis* in a perennial ryegrass seed crop. There is no information on how the herbicide performs in turf or under New Zealand climatic conditions.

Asulam is sold in New Zealand under the trade name Asulox for selectively removing docks (*Rumex* spp) from ryegrass based pastures and to kill bracken (O'Connor 1994). The herbicide is largely absorbed by the foliage and translocated through the plant but has some action through the soil. It is best used on soft spring and autumn growth. Research on the effect of asulam on *Poa trivialis* is limited to work done in UK pastures. Oswald *et al* (1972) found asulam at 2.8 kg/ha selectively suppressed *Poa trivialis* in a perennial ryegrass sward without any long term detrimental effects to the perennial ryegrass. Perennial ryegrass fully recovered 10 weeks after spraying. Visual symptoms of herbicide phytotoxicity on *Poa trivialis* plants were seen as paleness in colour and chlorosis of leaf tissue.

2.6.3 Dalapon

Dalapon is an aliphatic acid marketed for the selective control of annual and perennial grasses. The herbicide is absorbed by the foliage and roots and translocates readily throughout the plant (O'Connor 1994). The mode of action is by inhibiting cell division in the meristematic regions of the plant. Dalapon causes leaves to become dark green in colour followed by chlorosis and necrosis.

Elliot & Allen (1964) found grasses vary in susceptibility to dalapon. Perennial ryegrass rated most resistant while browntop and *Poa trivialis* were the most susceptible grasses. The time of the season at which dalapon was applied and age of plants when treated affected species reaction, with perennial ryegrass particularly resistant in a mature sward in late spring.

More recent research by Oswald *et al* (1972) found dalapon applied at 2.8 kg/ha in summer successfully suppressed *Poa trivialis* without long term detriment to perennial ryegrass. Mueller-Warrant & Brewster (1986) also found that dalapon applied in spring at 1.7-2.2 kg/ha showed good promise for controlling established *Poa trivialis*, without adversely affecting perennial ryegrass in a seed crop.

A mixture of dalapon and TCA (a chlorinated aliphatic acid) is sold under the trade name Teedal in New Zealand and is used for improved selective control of barley grass *(Hordeum murinum)*, *Poa annua,* browntop and Yorkshire fog in pastures (O'Connor 1994). TCA complements dalapon by providing residual control of late germinating seeds through root uptake whereas dalapon provides initial knockdown through foliar activity (Ashton & Crafts 1981).

2.6.4 Fenoxaprop

Fenoxaprop is sold in New Zealand under the trade name Puma for selective control of grasses in cereal crops (O'Connor 1984). The herbicide is primarily absorbed through the foliage and tolerance to grasses is based on the plants metabolism rate ie differential rates of degradation (Mueller-Warrant 1991). Visual symptoms of damage appear as chlorosis followed by necrosis and eventually death of the plant. Growth ceases almost immediately but plant death may take up to four weeks (O'Connor 1994).

Mueller-Warrant (1990) found fenoxaprop controlled *Poa trivialis* in a perennial ryegrass seed crop when applied at 0.14 to 0.28 kg/ha in late winter through to early spring. Where seedling *Poa trivialis* dominated the weed population, they succumbed to the lowest rate of the herbicide. The highest rate (0.28 kg/ha or higher) was necessary to control established *Poa trivialis*. Delaying application of fenoxaprop until the arrival of warmer weather in late spring was suggested to improve control of *Poa trivialis*, but this also increased potential for perennial ryegrass injury.

To improve performance of fenoxaprop against some weed species O'Connor (1994) recommends adding the anti-evaporant surfactant D-C-Trate. This surfactant improves wetting and spreading and penetration through the waxy cuticle of target plants. The wetting agent improves the stability of the spray mixture, reduces foaming and reduces the rate of evaporation.

2.6.5 Propyzamide

The herbicide propyzamide (previous called pronamide) is sold in New Zealand under the trade name Kerb Flo (O'Connor 1994). Propyzamide has post-emergence activity against a wide range of grass species, and pre-emergence activity against both grasses and broad-leaved plants (Paxman & Forgie 1972). The herbicide is readily absorbed by the roots with very small amounts absorbed by leaves (Ashton & Crafts 1981).

While the precise mechanism of propyzamide herbicidal activity is not known, sensitive species, particularly grasses, characterise toxicity by marked inhibition of growth in the meristematic regions accompanied by lateral swelling and necrosis. Visual symptoms of post-emergence activity are slow to appear, the first being a reduction in growth. According to Paxman & Forgie (1972) a susceptible plant may go through a period when it becomes darker in colour, after which it gradually becomes chlorotic, necrotic and then eventually dies.

Trial work conducted in New Zealand by Paxman & Forgie (1972) found propyzamide applied to a Waikato pasture at 1.7 kg/ha in early spring successfully removed *Poa annua, Poa trivialis* and barley grass (*Hordeum murinum*) from a sward with only a 20 % reduction in perennial ryegrass. Paxman & Forgie (1972) also found that propyzamide differs in activity on perennial ryegrass depending on the time of application. Rates in excess of 0.75 kg/ha applied in early spring or 0.5 kg/ha in winter are likely to be too severe on perennial ryegrass to be acceptable. However, a single application of 0.3 to 0.5 kg/ha in early spring and winter respectively would appear to reduce weed grasses effectively without being too severe on perennial ryegrass. A table developed by Paxman & Forgie (1972) on sensitivity of pasture grasses to propyzamide shows a four fold difference in sensitivity between *Poa trivialis* and perennial ryegrass with 90 to 100% control of *Poa trivialis* achieved at a rate of 0.3 kg/ha.

Coats (1975) found *Poa trivialis* and perennial ryegrass maintained in the USA under putting green conditions were both extremely susceptible to late spring applications of propyzamide applied at rates of 0.28-1.15 kg/ha. A 50% reduction in perennial ryegrass and *Poa trivialis* growth rates were achieved with propyzamide applications of 0.14 and 0.07 kg/ha respectively. Application rates may need to change according to seasonal temperature changes in susceptibility of these plants.

2.6.6 Sulfonyl ureas

Sulfonyl urea herbicides have knockdown as well as residual activity. They are extremely active allowing chemical application at very low rates. The mode of action of sulfonyl ureas is to impede cell division by inhibiting biosynthesis of essential amino acids. The chemical is rapidly absorbed by plant foliage and roots and translocated throughout the plant. Susceptible plants cease growth almost immediately after post-emergence treatment and are killed in 7 to 21 days (Sionis *et al* 1985).

Metsulfuron is a sulfonyl urea sold in New Zealand under the trade name Escort for scrub weed control (O'Connor 1994). Popay *et al* (1985) found metsulfuron applied at 18g/ha seriously damaged perennial ryegrass and white clover in a New Zealand pasture trial. However, browntop was only temporarily reduced. Information on the susceptibility of *Poa trivialis* to the chemical was not evaluated.

Thifensulfuron (previously called thiameturon-methyl) is another sulfonyl urea sold under the trade name Harmony in New Zealand for post-emergence control of many broadleaved weeds in cereal crops (Sanders & Rahman 1994). According to Sionis *et al* (1985) best results are obtained in spring when weeds are actively growing. Unlike metsulfuron, thifensulfuron is rapidly broken down to non active substances by microbial action and chemical hydrolysis.

2.6.7 Substituted ureas

Substituted ureas are primarily active via uptake by the roots, although they can be applied to foliage using surfactants. Inhibition of photosynthesis is considered to be the primary mode of action. Affected plants become pale, chlorotic and finally necrotic. Contact scorch and/or wilting can also occur, but only at higher rates (Roberts 1982).

Linuron is a selective substituted urea herbicide sold in New Zealand for control of annual broadleaf weeds in vegetable crops (O'Connor 1994). The only study found on the use of linuron to selectively control *Poa trivialis* was done in the UK on a winter cereal crop. Harvey (1985) demonstrated linuron applied at 0.75 kg/ha gave good control of *Poa trivialis* at the seedling stage. There was no information found on how effective the herbicide controlled more mature *Poa trivialis*..

Methabenzthiazuron is a selective substituted urea sold in New Zealand under the trade name Tribunil for broadleaf weed control in various vegetable crops (O'Connor 1994). In two studies conducted in New Zealand, methabenzthiazuron has shown widespread control of *Poa annua* in grass seed crops. Henderson & Brock (1976) demonstrated methabenzthiazuron applied post-emergence at 2.0 kg/ha in autumn gave good control of *Poa annua* in a perennial ryegrass seed crop. Rolston & Hare (1986) discovered methabenzthiazuron applied post-emergence at 3.0 kg/ha effectively controlled *Poa annua* in browntop, phalaris (*Phalaris aquatica*) and tall fescue (*Fescue arundinacea*) seed crops. However, in both field experiments some crop phytotoxicity was experienced at these rates. Fryer & Makepeace (1978) recommend methabenzthiazuron at 1.6 kg/ha post-emergence for controlling *Poa annua* in winter wheat crops. Anon (1994a) found methabenzthiazuron applied at 1.7 kg/ha pre-emergence gave 90% control of *Poa trivialis* compared with 50% control at 3.0 kg/ha post-emergence in a perennial ryegrass seed crop. According to Budd & Evans (1972) methabenzthiazuron is most efficient in its effect on a fine seed bed and its action is delayed or reduced by prolonged dry conditions .

Diuron is broad spectrum substituted urea sold in New Zealand as a residual herbicide for long term non-selective weed control in waste land, irrigation channels and drainage ditches. The herbicide is also used for selective weed control (by depth protection) in orchards, vineyards and berry crops due to the chemical having low solubility in the soil (O'Connor 1994). Diuron is mainly root absorbed and therefore requires moisture to move the chemical into the germination zone for weed control. Mueller-Warrant & Brewster (1986) found diuron at a rate of 2.7 kg/ha gave excellent seedling control of *Poa trivialis* in a perennial ryegrass seed crop.

2.6.8 Isoproturon/Diflufenican

The chemicals isoproturon and diflufenican are sold together under the trade name Cougar for control of broad leaved weeds in cereal crops in New Zealand. The herbicide is both shoot and root absorbed giving good contact and residual activity against seedlings and germinating weeds. The herbicide acts by blocking the photosynthetic processes of the plant causing extensive bleaching and discolouration of new growth (O'Connor 1994).

Black and Hewson (1978) obtained good control of *Poa annua* and *Poa trivialis* in the UK with isoproturon at 2.1-2.5 kg/ha pre and post emergence. A later study in the UK by Harvey (1985), confirmed that isoproturon applied post-emergence at 2.1-2.5 kg/ha will give good control of *Poa* species in winter cereals. Furthermore, Wooley (1992) in the UK found that a pre-emergence spray application with isoproturon plus diflufenican at 2.1 and 0.4 kg/ha respectively gave virtually 100% control of all *Poa* species. Early post emergence treatment was more variable, with only about 50% control. Information on the susceptibility of established perennial ryegrass to this herbicide could not be found.

2.6.9 Mecoprop

Mecoprop is a phenoxy herbicide sold in New Zealand under the trade name Duplosan KV and is particularly suited for use in mixtures to control difficult broadleaf weeds in turf lawns. The chemical is systemic being absorbed through the leaves and translocated to the growing points where it affects plant respiration and cell division (O'Connor 1994). Visual symptoms on susceptible broad leaved plants appear as severe epinasty of leaves, stems and petioles with necrosis slow to develop (Roberts 1982).

Mecoprop has been used to control broadleaf weeds and clovers in Australian race tracks (Mac Cartney 1990). Preliminary work in the UK by Birnie (1984) on the effects of some agricultural herbicides on a range of field margin flora has shown that *Poa trivialis* is susceptible to an application rate of 2.4 kg/ha of mecoprop although normally mecoprop has little effect on grasses.

2.6.10 Dicamba

Dicamba is a benzoic acid herbicide sold in New Zealand for the control of difficult to kill broadleaved weeds in cereals, certain forage brassicas, maize pasture and turf areas. The herbicide is taken into the plant via the foliage and the roots. It is translocated to growing points of the plant, where it accumulates to affect cell division and enlargement (O'Connor 1994). Visual symptoms on broadleaved weeds appear hormonal, similar to symptoms found with mecoprop phytotoxicity, ie severe distortion of leaves stems and petioles with necrosis slow to develop (Roberts 1982).

2.6.11 Triclopyr

Triclopyr is a substituted pyridine herbicide sold in New Zealand under the trade name Grazon for the selective control of scrub weeds and broad leaf weed control in turf. The herbicide is very similar in structure to the 2,4,5-T molecule (now no longer on the market). It is absorbed mainly through the leaves and stems of the plant and translocated within the plant to interfere with cell division and elongation (O'Connor 1994). Information on the susceptibility of the chemical to *Poa trivialis* or perennial ryegrass could not be found.

2.6.12 Triazines

Triazine herbicides are used both pre and post emergence for mainly control of annual weeds. The main site of uptake of triazines is via the roots but some foliar uptake can occur, mainly with those having a higher water solubility. Translocation is by way of the apoplastic system. The basis of selectivity between species is attributable to different rates of degradation which are rapid in resistant plants and slow in susceptible plants. Their mechanism of action involves the inhibition of photosynthesis. Visual symptoms appear as chlorosis of leaves, general inhibition of growth and necrosis of the plant (Roberts 1982).

Atrazine is a triazine herbicide used for selective control of some annual grasses and most broadleaf weeds in maize, linseed and establish lucerne crops (O'Connor 1994). Mueller-Warrant & Brewster (1986) have shown atrazine applied pre-emergence at 1.4 kg/ha provides only fair to poor control of *Poa trivialis* seedlings in a perennial ryegrass seed. crop. However, atrazine applied at a rate 2 kg/ha provided excellent control.

Prometryne is a selective triazine herbicide sold in New Zealand under the trade name Gesagard for pre and post-emergence control of annual grasses and broadleaf weeds in vegetable crops (O'Connor 1994). According to Arthur & Shildrick (1966) prometryne applied post-emergence at a rate of 2.24 kg/ha, controlled *Poa trivialis* at the seedling stage in a well-established perennial ryegrass seed crop.

2.6.13 Pendimethalin

Pendimethalin is a selective dinitroanaline sold in New Zealand under the trade name Stomp 330E for the control of annual grasses and broadleaf weeds in maize and vegetable crops (O' Connor 1994). The chemical is readily absorbed by roots and shoots but only slightly translocated. Several biochemical processes in the plant can be altered such as photosynthesis, protein and lipid synthesis. Symptoms appear soon after germination with severe stunting of shoots and roots. At lower rates foliage becomes dark green before the onset of necrosis (Roberts 1982).

In a British study, pendimethalin applied pre-emergence at 1.3-2.0 kg/ha gave 90% control of *Poa* species in winter cereals (Harvey 1985). Information on the susceptibility of perennial ryegrass to the chemical could not be found.

2.7 Concluding comments

In conclusion, a considerable amount of work has been undertaken investigating the removal of *Poa trivialis* seedlings from a established perennial ryegrass seed crop or pasture sward. However, little information is avaliable on how to selectively remove established *Poa trivialis* from a mature perennial ryegrass turf. The trials described in Chapter 3 are designed to provide this information based on herbicides having shown promising results on *Poa trivialis* from this review.

3. METHODS AND MATERIALS

3.1 INTRODUCTION

To achieve the objectives outlined in Chapter 1, a range of herbicides were tested in three trials (a field trial and two pot trials) during 1995. The trials were essentially screening herbicides for selectivity *i.e.* tolerance of perennial ryegrass and damage to *Poa trivialis* swards under Palmerston North, New Zealand conditions. A further trial was conducted to determine whether herbicide residues could affect the germination of perennial ryegrass seed sown soon after treatment using a bioassay.

3.2 TRIAL 1 (INITIAL SCREENING POT TRIAL)

A pot trial conducted at Massey University Plant Growth Unit tested a range of post-emergence herbicides on perennial ryegrass and *Poa trivialis* using a completely randomised block design. Treatments showing useful activity and selectivity were further assessed in a field trial (Trial 2).

There were 20 treatments, including one untreated control, with 5 replicates of each. Clumps of *Poa trivialis* from a lawn and perennial ryegrass from a sheep pasture were obtained on 20 June 1995. Plants of similar size were transplanted into size PB3 Planta bags (black polythene bags) containing moistened soil. The soil used as the potting medium was a Manawatu silt loam obtained from a recently cultivated paddock at Massey University's Frewens site. This soil is relatively free draining with a low nutrient status (refer Appendix 1 for soil test).

Plants were trimmed at the time of transplanting, left for a 2 weeks to allow adequate recovery from stress before treatments were applied on 14 July 1995. All plants were healthy at the time of spraying. For the 16 hours preceding and after spraying transplants were maintained inside a glasshouse at 20 ^{0}C, without watering to improve spray efficacy.

3.2.1 Treatments

Herbicides selected for testing (Table 3.1) are all those avaliable on the New Zealand market that appear to have potential to selectively control *Poa trivialis* in perennial ryegrass swards based on available information (refer Section 2.6). Application rates were based on rates used in published trial results for *Poa trivialis* or perennial ryegrass, or recommended rates for weed control in other crops in New Zealand (O'Connor 1994).

Table 3.1 Treatments applied at post-emergence to potted *Poa trivialis* and perennial ryegrass at the Plant Growth Unit Massey University on 14 July 1995

ACTIVE INGREDIENT		TRADE NAME	
Name	Rate (kg/ha)	Name	Rate/ha
asulam	1.6	Asulox	4.0 L
atrazine	2.0	Flowable Atrazine	4.0 L
chlorpropham	2.5	Chloro-IPC	6.25 L
dalapon	1.5	Chemagro Dalapon	2.0 kg
dalapon + TCA	0.99 + 5.7	Teedal	9.0 kg
dicamba	0.9	Banvel 200	3.0 L
diuron	2.6	Karmex	3.3 L
ethofumesate	2.0	Nortron 500 SC	4.0 L
fenoxaprop	0.15	Puma S	2.0 L
isoproturon + diflufenican	2.0 + 0.4	Cougar	4.0 L
linuron	2.0	Linuron	4.0 kg
mecoprop	1.6	Duplosan K V	2.6 L
methabenzthiazuron	2.0	Tribunil	2.8 kg
metsulfuron	0.03	Escort	50g
pendimethalin	2.0	Stomp 330E	6.0 L
prometryne	1.0	Gesagard 50 WP	2.0 kg
propyzamide	0.10	Kerb Flo	0.25 L
thifensulfuron-methyl	0.015	Harmony	20g
triclopyr	1.8	Grazon	3.0 L
untreated			

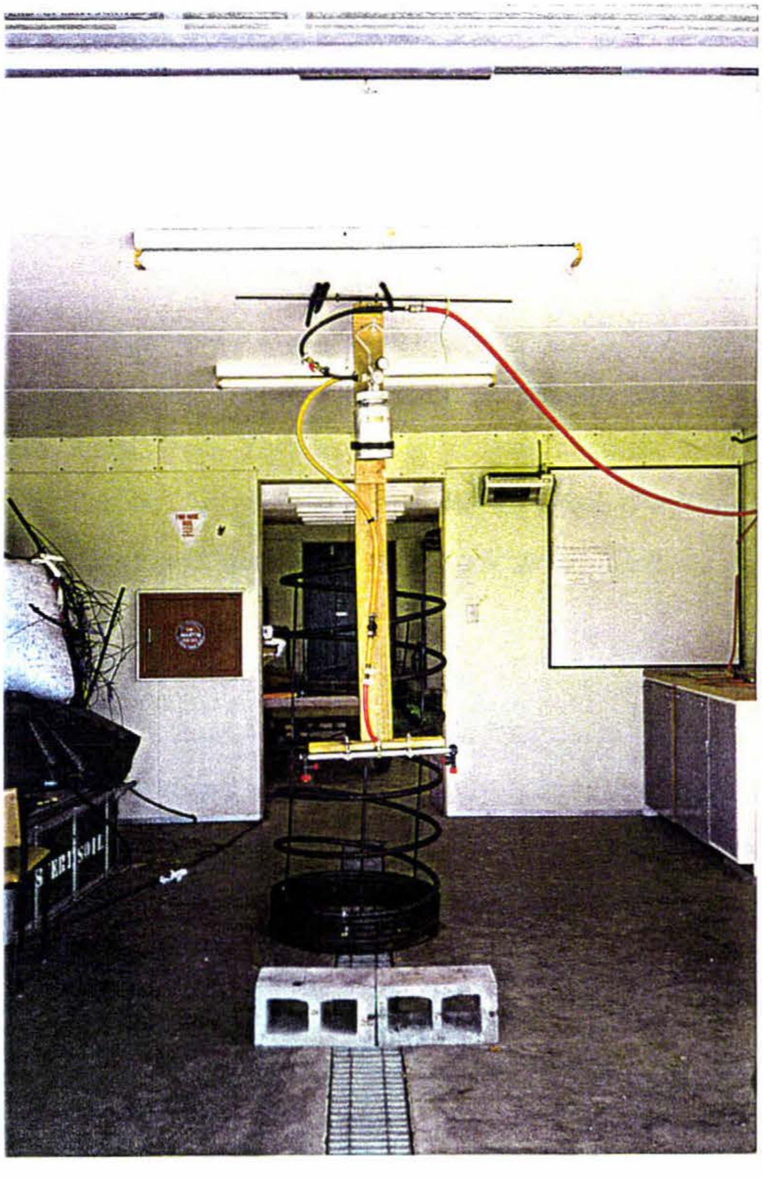
3.2.2 Spray application

Herbicides were applied using a "swinging pendulum sprayer" in which constant pressure was supplied from a compressed air system as described by Wiese (1977). A pressure regulator was set to give a constant application pressure of 200 kPa forcing the spray through two fan nozzles (Lurmark A4-F110) 40 cm apart (refer Plate 3.1). Plants were sprayed by letting the device swing from a set height (a marked point on the steel spiral stand) and allowing it to pass back and forth once whilst spraying the pots below. The sprayer was then caught and the valve closed to stop spraying. The sprayer was calibrated before treatments by calculating and weighing the volume of droplets applied to a dry glass strip before and after spray application. A water rate of 250 L/ha was used for all treatments. The spray tank was emptied and rinsed between treatments to avoid any contamination.

3.2.3 Measurements

The treated pots were placed at a sheltered outdoor site of Massey University Plant Growth Unit and monitored following spraying. Plants were scored for damage on the 4 August 1995 (3 weeks after spraying) when damage symptoms first became apparent in some treatments, and thereafter every week until 6 October 1995 (12 weeks after spraying). Plants were harvested in each pot on the 24 November 1995 (19 weeks after spraying). The plants in each pot were cut at ground level and the fresh weights recorded.

Plate 3.1: The "swinging pendulum sprayer" which was used in the pot trials



3.3 TRIAL 2 (FIELD TRIAL)

A field trial was conducted at the Awapuni Racecourse, Palmerston North, on the outside of the back straight. This trial tested the six most promising treatments for control of *Poa trivialis* from Trial 1 under field conditions. A randomised block design was used with four replicates per treatment.

The racetrack sward consisted of a mixture of grasses and broadleaved weeds. The main grass species present were *Poa trivialis,* perennial ryegrass, browntop and *Poa annua.* Other grasses found were Yorkshire fog (*Holcus lanatus*), prairie grass (*Bromus willdenowii*), cocksfoot (*Dactylis glomerata*) and tall fescue (*Festuca arundinacea*). The broadleaved species found were white clover, chickweed *(Stellaria media*), and yarrow (*Achillea millefolium*).

The soil type at the trial site was a Manawatu fine sandy loam, well to moderately drained, underlain by loose sands and weakly packed gravels and stones within 3 metres of the surface. The site elevation was approximately 60 m above sea level with an average monthly rainfall of 120mm and temperature of 12.5 ^{0}C over the trial period (refer to Appendix 2).

Areas where *Poa trivialis* was present were mapped out and 27 plots (3.0 x 5 m in size) marked along a row. Point analysis was carried out to determine the density of *Poa trivialis* and other grasses in each plot (100 points per plot). Plots were then blocked for density of *Poa trivialis* as the species varied substantially between plots (Table 3.2).

Table 3.2: Block designations for ground cover % of *Poa trivialis* in the field trial.

BLOCK	1	2	3	4
Poa trivialis	Low	medium low	medium high	High
Ground cover %	14-20%	21-25%	28-32%	34-43%

The main reasons for carrying out point analysis for botanical analysis rather than other methods such as harvesting quadrats were the greater ease of identifying grass species in a living state, that is was a non destructive method and that assessment was for the whole area rather than a small proportion of each plot.

Plate 3.2: The field site on the day of application, 3 October 1995

3.3.1 Treatments

The field trial compared six herbicide treatments with the untreated control (Table 3.3). At the time of spraying all plants look healthy with no signs of nutrient deficiency.

Table 3.3: Treatments applied to field plots of *Poa trivialis* at Awapuni Racecourse on 3 October 1995

ACTIVE INGREDIENT		TRADE NAME	
Name	Rate (kg/ha)	Name	Rate /ha
asulam	2.4	Asulox	6 L
chlorpropham	2.5	Chloro IPC	6.3 L
dalapon	2.2	Chemagro Dalapon	3 kg
ethofumesate	2.0	Nortron	4 L
fenoxaprop + oil	0.15	Puma S	2 L
		D-C-Trate	*
propyzamide	0.2	Kerb Flo	0.5L
untreated			

* DC-Trate was added to fenoxaprop at 5 mls per litre of mix solution.

Propyzamide, dalapon and asulam had no damaging effect on perennial ryegrass in Trial 1. In an effort to improve efficacy on *Poa trivialis,* these three chemicals were used at higher rates in the field trial. Fenoxaprop was tested at a commonly recommended rate for weed control. It was included in combination with D-C-Trate (an anti-evaporant surfactant) to improve efficacy.

3.3.2 Spray application

All herbicide treatments were applied on 3 October 1995. Weather conditions were fine with some cloud and calm at the time of spray application (see Appendix 2). Air and soil temperature (10cm) recorded in the morning for Palmerston North at AgResearch Grasslands was 13.6 °C and 13.5 °C respectively, and ground conditions were moist.

Herbicides were applied using a gas powered backpack sprayer in which constant pressure was supplied from a liquid petroleum gas (LPG) cylinder. A pressure regulator was set to give a constant application pressure of 200 kPa forcing the spray through four fan nozzles (Hardi 4110-12) at 34 cm nozzle spacing angled at 5° on a hand-held boom. The sprayer was calibrated before use to ensure correct operation and application rates. A water rate of 257 L/ha was used for all treatments, and the spray tank emptied out and rinsed between treatments. The sward height at the time of spraying was 100 mm across the treated plots. The sward was not mown until 11 days after application.

3.3.3 Measurements

Plots were initially assessed visually for general appearance and health of *Poa trivialis* and perennial ryegrass on 22 October 1995 (2 weeks after spraying). Point analysis was carried out to determine changes in ground cover composition on 18 November 1995 (6 weeks after spraying). Identification of grasses was made using the leaf blade. A final assessment of turf density was made on 17 December 1995 (10 weeks after spraying). For all assessments the outside 0.5 metres surrounding the plots were not used to allow for any edge effects (eg from spray drift) between the plots.

3.4 TRIAL 3 (SECOND SCREENING POT TRIAL)

A further pot trial was conducted in October 1995 to obtain information on the more promising herbicides identified in Trial 1. A completely randomised block design was used. In total there were 17 treatments in this trial and an untreated control, each replicated four times. Methods and materials were similar to Trial 1, with plants being obtained from the same sites and transplanted into bags (PB3's) of the same soil type *i.e.* Manawatu silt loam. Plants were trimmed at transplanting. They were left for 3 weeks following transplanting to allow adequate recovery from stress before treatments were applied on 19 October 1995.

3.4.1 Treatments

Fenoxaprop was tested at 0.15, 0.30, 0.60 kg/ha with the addition of D-C-Trate to compare the relative susceptibility of *Poa trivialis* and perennial ryegrass. Fenoxaprop was also applied with a picloram/triclopyr mix and with MCPA to investigate compatibility with broad leaved herbicides.

Asulam, propyzamide, dalapon and an isoproturon/diflufenican mix were tested at different rates (Table 3.4) to determine the susceptibility of *Poa trivialis* and perennial ryegrass to higher rates of each herbicide.

Ethofumesate and thifensulfuron were tested at rates higher than recommended by O'Connor (1994) to determine the susceptibility of both grasses and investigate whether warmer conditions may influence effectiveness of theses two herbicides as both had shown no effect in the first pot trial.

A turf growth regulator sold under the trade name Primo (active ingredient, trinexapac-ethyl) was also tested as recent trial work by a chemical company indicated promising results in suppression of *Poa annua*, in perennial ryegrass swards (Anon 1994b).

Table 3.4: Treatment applied at post-emergence to potted *Poa trivialis* and perennial ryegrass at the Plant Growth Unit Massey University on 19 October 1995.

ACTIVE INGREDIENT		TRADE NAME	
Name	Rate (kg/ha)	Name	Rate/ha
asulam	2.0	Asulox	5.0 kg
asulam	4.0	Asulox	10 kg
dalapon	3.0	Chemagro Dalapon	4.0 kg
dalapon	4.4	Chemagro Dalapon	6.0 kg
ethofumesate	3.0	Nortron 500 SC	6.0 L
fenoxaprop	0.15	PumaS	2.0 L
fenoxaprop + oil	0.15	PumaS+ D-C-Trate	2.0 L
fenoxaprop + oil	0.30	PumaS+ D-C-Trate	4.0 L
fenoxaprop + oil	0.60	PumaS+ D-C-Trate	6.0 L
fenoxaprop +	0.15	Puma S	2.0 L
picloram	0.20	Tordon brushkiller	2.0 L
triclopyr	0.60		
fenoxaprop +	0.15	PumaS	2.0 L
MCPA	1.5	MCPA	4.0 L
isoproturon + diflufenican	2.0 + 0.4	Cougar	4.0 L
isoproturon + diflufenican	3.0 + 0.6	Cougar	6.0 L
propyzamide	0.20	Kerb Flo	0.50 L
propyzamide	0.40	Kerb Flo	1.0 L
thifensulfuron-methyl	0.03	Harmony	40 g
trinexapac-ethyl	0.75	Primo	3.0 L
untreated			

3.4.2 Spray application

The same spraying technique as used for Trial 1 was carried out for Trial 3 (refer to Section 3.2.2). After spraying *Poa trivialis* pots were placed under shade cloth at Massey University Plant Growth Unit (Plate 3.3) to produce optimal growing conditions for the grass species. Previous experience had shown that *Poa trivialis* grows poorly when exposed to full light intensity. Perennial ryegrass pots were not placed under shade cloth as this species is better adapted to growing in full sunlight.

3.4.3 Measurements

The plants were monitored and scored for visual damage on 6 November 1995 (3 weeks after spraying) and at weekly intervals following this until 9 January 1996 (12 weeks after spraying). A controlled release fertiliser (Osmocote Plus) was applied at 8 grams per pot to all plants on 30 November 1995, (6 weeks after spraying). All foliage of perennial ryegrass and *Poa trivialis* pots was harvested, weighed and recorded on 14 January 1995 (13 weeks after spraying).

Plate 3.3: The sheltered outdoor site at Massey University Plant Growth Unit where the 2nd pot trial was carried out with the *Poa trivialis* pots in the foreground under shade cloth.

3.5 TRIAL 4 (RESIDUE PERSISTANCE BIOASSAY)

This trial was conducted to determine whether herbicide residues used in the field trial (refer Table 3.3 for treatments) could affect germination of ryegrass seed sown soon after spraying. The bioassay determines herbicide residual effect by testing seedling germination in treated soil and comparing this with the germination from untreated soil samples.

From each of the treatment field plots, including the untreated control, 10 core samples (40 mm deep and 50 mm wide) were taken on 24 October 1995 (3 weeks after spraying). The soil from each plot was bulked together air dried (over 8 hours), sifted to remove vegetation (grass roots etc), placed in individual planter pots and labelled. The following day six perennial ryegrass (cv Ellett) seeds were sown by hand 2mm below the soil surface of each pot. Pots were then placed in a stand-out area at Massey University's Plant Growth Unit and watered daily by hand.

Before sowing, a germination test was carried out on the seed lot used in the bioassay at Massey University Seed Technology Centre (Plate 3.4). A total of 50 seeds, replicated twice were placed on moist blotting paper in a petri dish and placed into a growth cabinet running at 30 °C and light for 12 hours and 20 °C without light for 12 hours in a repeated cycle. Seed germination was assessed after 14 days in the growth cabinet. The results showed a 95% seed germination capacity.

3.5.1 Measurements

Seedling emergence of perennial ryegrass was recorded for each pot on 1 November 1995 (7 days after planting). Seedlings were monitored for plant vigour (ie growth and visual appearance) over the following weeks. On 1 December 1995 (5 weeks after planting), shoots of perennial ryegrass were harvested and fresh weights recorded for each pot.

Plate 3.4: The pots of the germinated perennial ryegrass (*Lolium perenne*) seeds, cultivar "Ellett" that were used in the seed germination test at the Massey University Plant Growth Unit.

3.6 DATA ANALYSIS

Data was analysed using the "SAS" statistical analysis computer programme. A one-way analysis of variance was used to analyse data, and means were compared by the LSD multiple range test.

4. RESULTS

4.1 TRIAL 1 (INITIAL SCREENING POT TRIAL)

All visual damage scores were based on a 1 to 10 gradient system. A score of 1 was given to pots where all plants appeared healthy, a score of 5 to pots with moderate damage, and 10 where all plants were dead.. Scores were given in between these numbers depending on severity of damage.

4.1.1 *Poa trivialis* (visual damage scores)

Three weeks following spraying, the isoproturon/diflufenican mix and atrazine treatment caused significantly (P = 0.05) more damage to *Poa trivialis* than all other treatments except for diuron (Table 4.1). Visual symptoms of herbicide damage on the *Poa trivialis* plants for both treatments appeared as scorching of leaf tips followed by necrosis. The effect of diuron was seen as scorching, distortion and yellowing of the leaves. Other treatment plants exhibited no obvious phytotoxic effects.

Six weeks following spraying, atrazine, diuron and fenoxaprop caused significantly (P = 0.05) more damage to *Poa trivialis* than all other treatments. Visual symptoms of atrazine damage appeared as scorching of the leaves, yellowing of the leaves followed by necrosis (Plate 4.1). Visual symptoms of diuron damage appeared similar to atrazine but more severe with some dead plants (Plate 4.2). Fenoxaprop damage appeared as paleness, reddening of leaves, followed by necrosis (Plate 4.3). The scorching detected on isoproturon/diflufenican leaves 3 weeks after spraying was still evident. All other treatments were not significantly different from the untreated control.

Twelve weeks following spraying, the fenoxaprop treatment had caused significantly (P=0.05) more damage to *Poa trivialis* than all other treatments. Fenoxaprop treated plants were dead or close to death at the time of assessment. All other treatments showed no significant differences in damage scores compared with the untreated control. The severe scorching of plants by the isoproturon/diflufenican mix was not evident 12 weeks after spraying, with all *Poa trivialis* plants fully recovered (refer Plate 4.4 & Plate 4.5).

Table 4.1: The effect of herbicides 3, 6 and 12 weeks after being applied to transplanted *Poa trivialis* in pots on 14 July 1995

Treatment	kg ai/ha	Time of assessment		
		Week 3	Week 6	Week 12
asulam	1.6	1.4 fg	3.4 cd	3.0 cde
atrazine	2.0	4.2 a	6.0 ab	3.8 bcd
chlorpropham	2.5	2.0 def	3.8 c	3.4 bcde
dalapon	1.5	2.4 cde	3.4 cd	3.0 cde
dalapon +TCA	0.99 + 5.8	2.2 def	3.4 cd	4.8 cb
dicamba	0.9	2.2 dfe	2.8 cde	2.6 de
diuron	2.6	4.0 ab	6.8 a	5.2 b
ethofumesate	2.0	1.4 fg	2.4 de	3.2 bcde
fenoxaprop	0.15	2.6 cd	5.2 b	8.6 a
isoproturon + diflufenican	2.0 + 0.4	4.2 a	3.8 c	1.6 e
linuron	2.0	3.2 bc	2.2 de	1.6 e
mecoprop	1.6	2.0 def	2.8 cde	2.8 cde
methabenzthiazuron	2.0	2.6 cd	2.0 e	2.8 bcd
metsulfuron	0.03	2.2 def	2.8 cde	2.6 de
pendimethalin	2.0	1.6 efg	2.4 de	2.4 de
prometryne	1.0	1.0 g	2.2 de	3.0 cde
propyzamide	0.1	2.2 def	2.6 cde	4.0 bcd
thifensulfuron-methyl	0.015	1.4 fg	2.2 de	3.4 bcde
triclopyr	1.8	1.4 gf	1.8 e	3.4 bcde
untreated		1.8 defg	2.4 de	3.2 bcde

- Means within a column followed by the same letter are not significantly different at the 5% level.

Plate 4.1: ***Poa trivialis*** **6 weeks after treatment with atrazine.**

Score 6

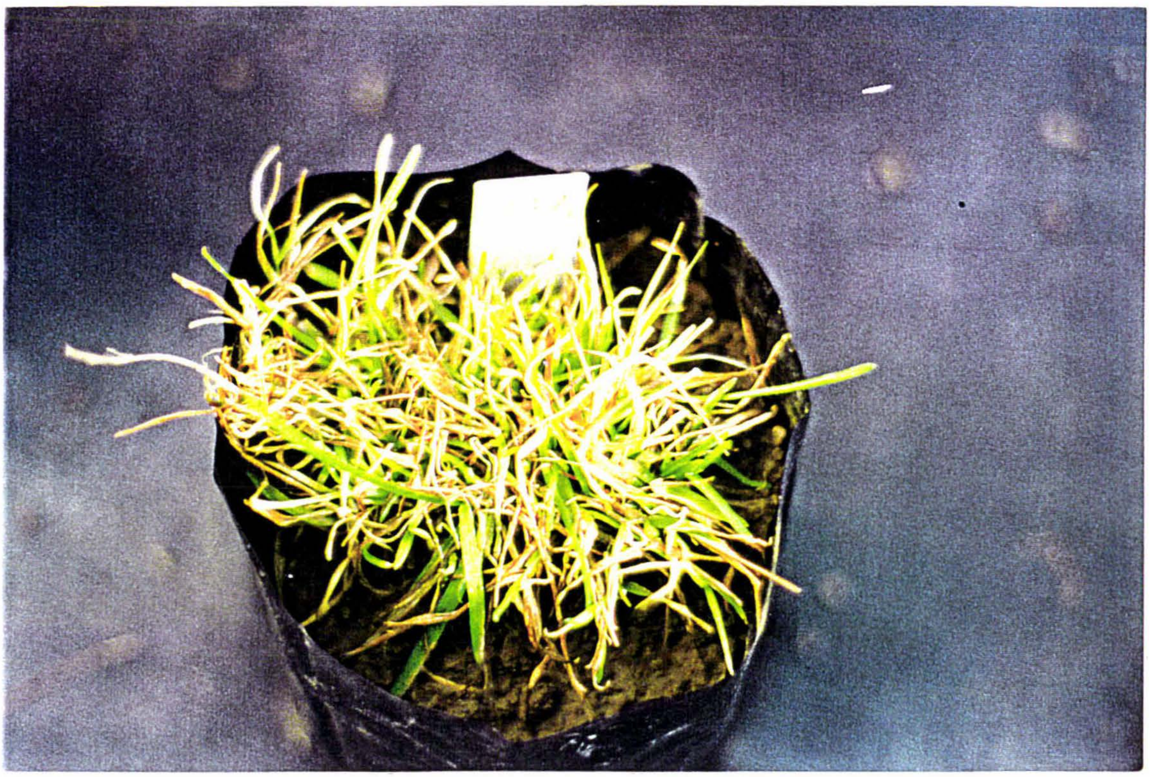


Plate 4.2: *Poa trivialis* 6 weeks after treatment with diuron.

Score 9

Plate 4.3: ***Poa trivialis*** **6 weeks after treatment with fenoxaprop.**

Score 6

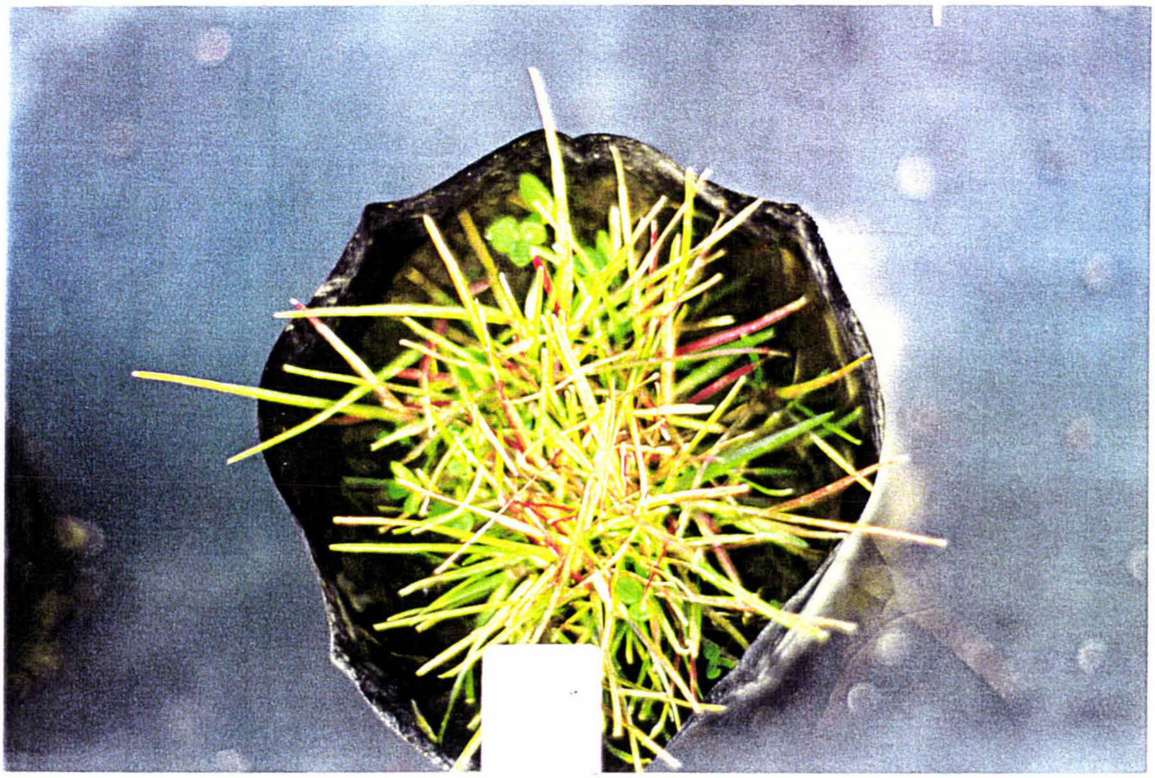


Plate 4.4: *Poa trivialis* 6 weeks after treatment with isoproturon/diflufenican mixture.

Score 8

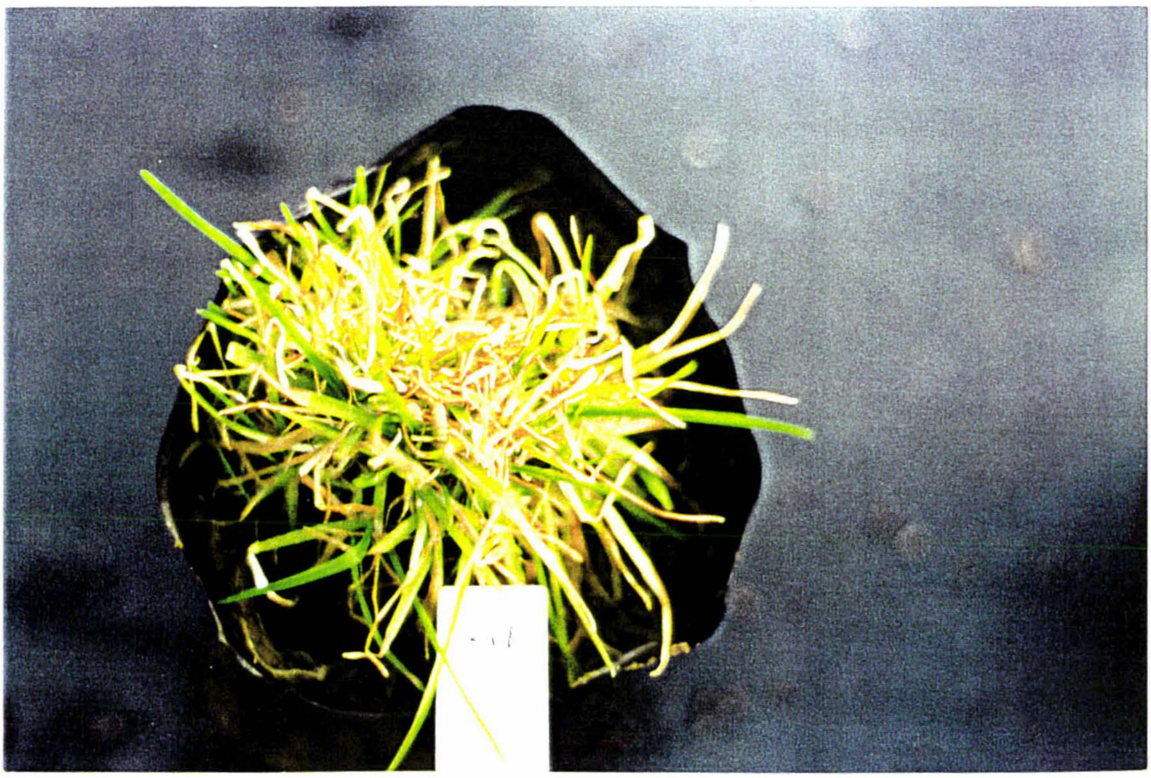


Plate 4.5: *Poa trivialis* 12 weeks after treatment isoproturon/diflufenican mixture

Score 1

4.1.2 Perennial ryegrass (visual damage scores)

Three weeks following spraying, no significant (P = 0.05) damage to the perennial ryegrass was detected for any treatment (Table 4.2).

Six weeks following spraying, diuron caused significantly (P = 0.05) more damage to perennial ryegrass than all other treatments. Visual symptoms of damage appeared as chlorosis, wilting, distortion and necrosis of the leaves (Plate 4.6). Visual damage scores from atrazine, metsulfuron, and the dalapon/TCA mixture were significantly higher than the untreated control. All other treatments were not significantly different from the untreated control (Plate 4.7).

Twelve weeks following spraying, both diuron and atrazine had caused significantly (P=0.05) more damage to perennial ryegrass than other treatments. All plants in both treatments showed signs of chlorosis wilting and distortion with no signs of recovery. All other treatments were not significantly different from the untreated control.

Table 4.2: The effect of herbicides 3, 6 and 12 weeks after being applied to transplanted perennial ryegrass plants in pots on 14 July 1995.

Treatment	kg ai/ha	Time of assessment		
		Week 3	Week 6	Week 12
asulam	1.6	1.4 ab	2.6 bcd	2.2 b
atrazine	2.0	1.2 ab	3.4 b	4.6 a
chlorpropham	2.5	1.4 ab	1.8 def	2.2b
dalapon	1.5	1.4 ab	2.6 bcd	2.6 b
dalapon + TCA	0.99 + 5.7	1.6 ab	2.8 bc	2.0 b
dicamba	0.9	1.0 b	1.8 def	2.4 b
diuron	2.6	1.2 ab	4.4 a	6.0 a
ethofumesate	2.0	1.2 ab	1.8 def	2.2 b
fenoxaprop	0.15	1.2 ab	2.2 cdef	1.6 b
isoproturon + diflufenican	2.0 + 0.4	1.0 b	2.0 cdef	2.4 b
linuron	2.0	1.0 b	2.0 cdef	2.2 b
mecoprop	1.6	1.6 ab	2.4 bcd	2.2 b
methabenzthiazuron	2.0	1.2 ab	1.8 def	2.2 b
metsulfuron	0.03	1.8 a	3.4 b	3.0 b
pendimethalin	2.0	1.0 b	1.8 def	2.4 b
prometryne	1.0	1.0 b	1.8 def	2.4 b
propyzamide	0.1	1.0 b	1.6 ef	2.0 b
thifensulfuron-methyl	0.015	1.4 ab	2.2 cdef	2.0 b
triclopyr	1.8	1.0 b	1.4 f	1.8 b
untreated		1.2 ab	1.8 def	2.6 b

- Means within a column followed by the same letter are not significantly different at the 5% level.

Plate 4.6: Perennial ryegrass 6 weeks after treatment with diuron

Score 10

Plate 4.7: Perennial ryegrass 6 weeks after treatment (untreated control)

Score 1

4.1.3 Shoot fresh weights

The results of the fresh weights at harvest for *Poa trivialis* and perennial ryegrass in Trial 1 are presented in Figure 4.1 and Figure 4.2 respectively.

In the *Poa trivialis* pot trial, the average fresh weights for plants treated with fenoxaprop, diuron, dalapon/TCA, atrazine and chlorpropham treatments were significantly ($P = 0.05$) less than the untreated control. This corresponds with the higher damage scores recorded for *Poa trivialis* by these treatments.

In the perennial ryegrass pot trial, diuron was the only herbicide that had a significantly ($P = 0.05$) lower average fresh weight compared with the untreated control. All other treatments showed no significant difference compared with the untreated control.

Results from the first trial suggest diuron is unlikely to be sufficiently selective for use in a perennial ryegrass sward at an application rate necessary to control *Poa trivialis*. However, fenoxaprop, dalapon, atrazine, and chlorpropham are worth further consideration. Other treatments such as dicamba, linuron, mecoprop, methabenzthiazuron, metsulfuron, pendimethalin and linuron showed little effect on either grass species at applied rates and were not considered for later trials.

Figure 4.1: The average fresh weight of *Poa trivialis* shoots harvested from pots on 24 November 1995, 19 weeks after application of the herbicides

Bars to the left of the graph join treatments which are not significantly different at P = 0.05.

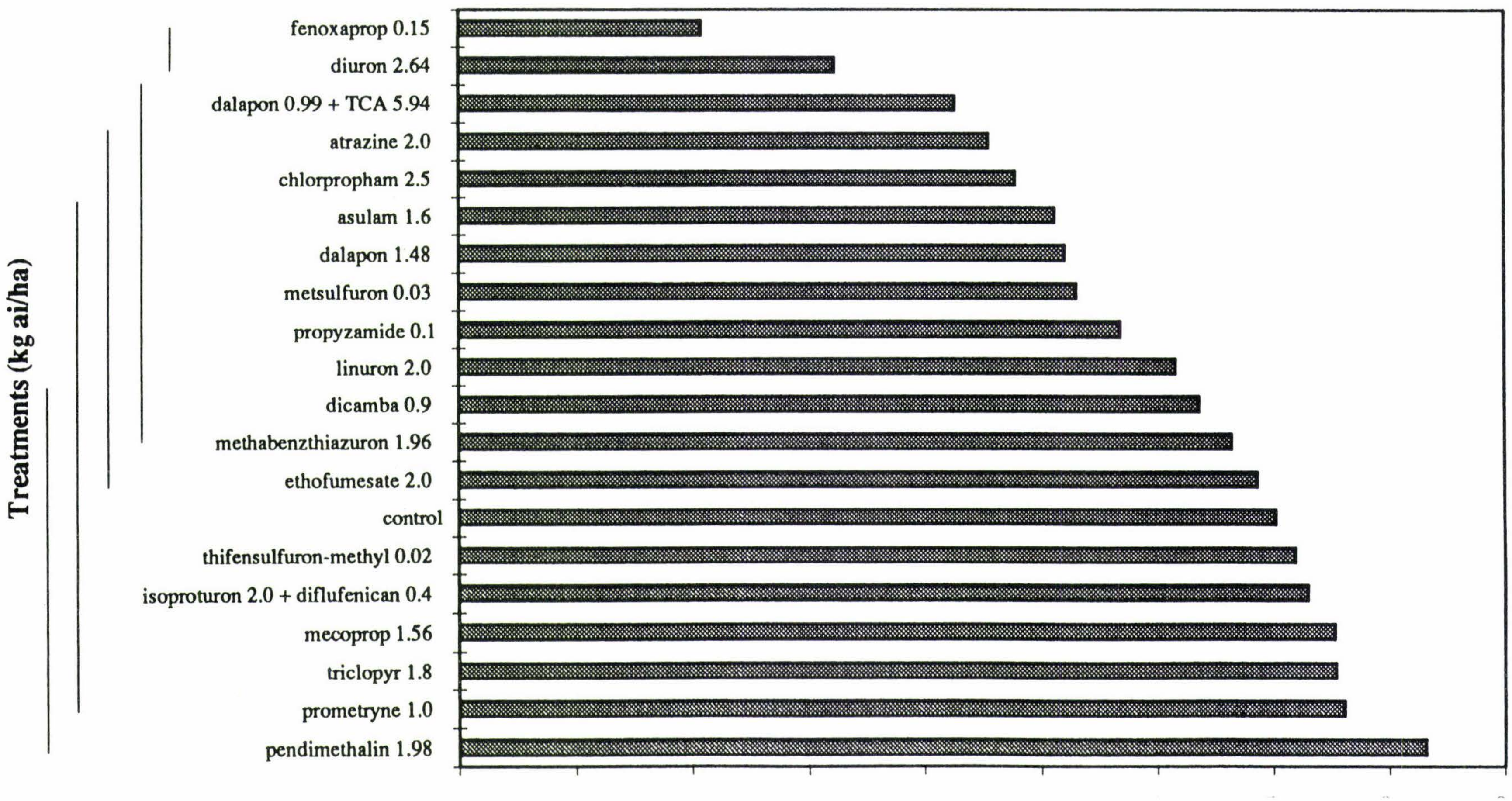
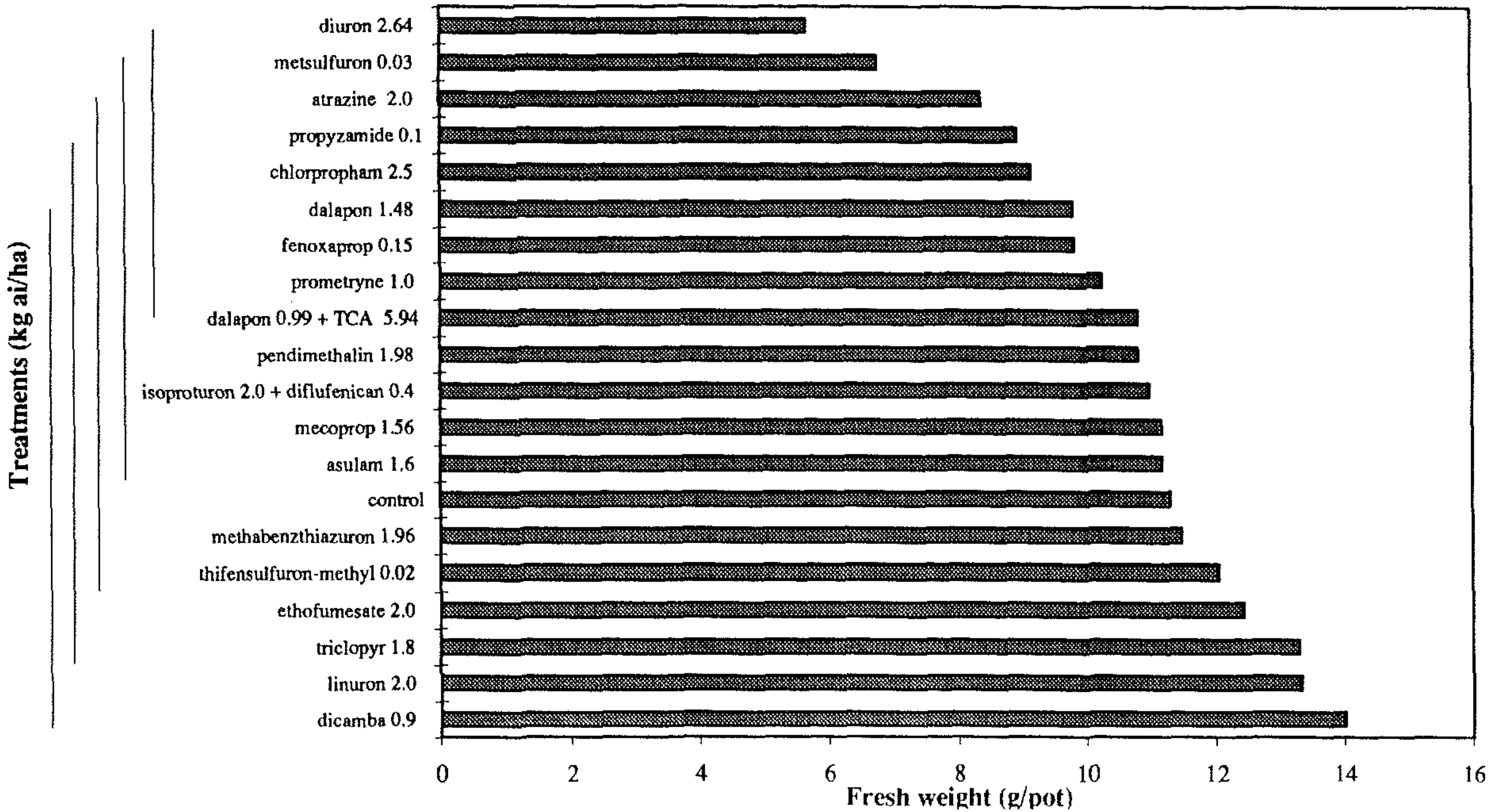


Figure 4.2 The average fresh weight of perennial ryegrass shoots harvested from pots on 24 November 1995, 19 weeks after the application of the herbicides.

Bars to the left of the graph join treatments which are not significantly different at P = 0.05.



4.2 TRIAL 2 (FIELD TRIAL)

In the field trial visual assessment by scoring was used to analyse damage caused to grasses and changes in ground cover density within treatment plots. Quantitative assessment in the form of point analysis was used to assess the changes in sward composition within each treatment plot.

4.2.1 *Poa trivialis* (visual damage scores)

Two weeks following spraying, dalapon, asulam, propyzamide and fenoxaprop treatments had caused significant (P= 0.05) damage to *Poa trivialis* compared with the untreated control (Table 4.3). Symptoms of dalapon, asulam and propyzamide herbicide damage appeared as stunting, leaves yellowing followed by necrosis. Symptoms of fenoxaprop herbicide damage appeared as paleness and reddening of leaves.

4.2.2 Perennial ryegrass (visual damage scores)

Two weeks following spraying, damage scores for perennial ryegrass were similar to those exhibited by *Poa trivialis* (Table 4.3). Both dalapon and asulam had caused significantly (P = 0.05) more damage to perennial ryegrass than any of the other treatments. Visual symptoms appeared as yellowing leaves, distortion and necrosis of the plant. Other treatments such as propyzamide, fenoxaprop and chlorpropham caused significant damage to perennial ryegrass compared to the untreated control. Ethofumesate caused no significant damage to perennial ryegrass compared with the untreated control.

Table 4.3: The effect of herbicides applied in the field trial on 22 October 1995 to *Poa trivialis* and perennial ryegrasss 2 weeks after spraying.

Treatment	kg ai/ha	*Poa trivialis*	Perennial ryegrass
ethofumesate	2.0	1.5 d	1.5 cd
chlorpropham	2.5	4.5 c	2.8 bc
asulam	2.4	8.0 ab	5.8 a
dalapon	2.2	8.8 a	6.5 a
fenoxaprop + oil	0.15	6.5 b	3.3 b
propyzamide	0.2	7.3 ab	3.8 b
untreated		1.8 d	1.3 d

- Means within a column followed by the same letter are not significantly different at the 5% level.

4.2.3 Change in sward composition

The results of sward composition for each treatment before and 6 weeks after spraying are presented in Figure 4.3 and Figure 4.4 respectively.

With regard to *Poa trivialis* control, four of the six herbicide treatments used were effective. Before spraying, average ground cover across the trial site for *Poa trivialis* was 25%. At the 6 week assessment average *Poa trivialis* ground cover content for each of the treatments had change considerably. A single application of dalapon, asulam, fenoxaprop and propyzamide reduced the levels of *Poa trivialis* on average to 2%, 7%, 7% and 12% respectively in the treated plots. This was compared to 22% *Poa trivialis* found in untreated plots. Chlorproham caused only a minor reduction to 20% in *Poa trivialis* content. Ethofumesate caused no damage to *Poa trivialis* with an average increase in ground cover content to 28% measured for these plots.

With regard to perennial ryegrass tolerance, four of the six treatments proved acceptable. A substantial increase (30 % or more) in the species was experienced in the ethofumesate, propyzamide and chlorpropham treatment plots. Fenoxaprop treated plots showed only a minor increase in perennial ryegrass content when compared with the untreated control.

However, both dalapon and asulam caused a substantial reduction (25% or more) in perennial ryegrass content with in the treated sward plots.

With regard to *Poa annua* control, five of the six herbicides gave some control. At assessment 6 weeks after application the untreated plots averaged 13% *Poa annua* ground cover, a rise of 14% over the trial period. A single application of chlorpropham, propyzamide, dalapon, ethofumesate and asulam reduced the levels of *Poa annua* on average by 65%, 50%, 40%, 35% and 15% respectively in the treatment plots. Fenoxaprop was the only herbicide that had no effect on *Poa annua* with a substantial increase of 40% experienced in the treated plots.

Browntop ground cover was effected by three of the six herbicides used. A single application of dalapon, asulam or fenoxaprop substantially reduced the levels of browntop by 30% or more in ground cover content in treated plots. Ethofumesate and chlorpropham showed only minor reductions in browntop content compared with the untreated control. Propyzamide showed an increase in browntop content of 12% in the treatment plots.

With regard to broadleaved species, white clover was completely removed by ethofumesate in treated plots and a large increase in yarrow was experienced in both dalapon and asulam treated plots.

Figure 4.3: The average ground cover (%) in plots on 28 September 1995 (a week before spraying).

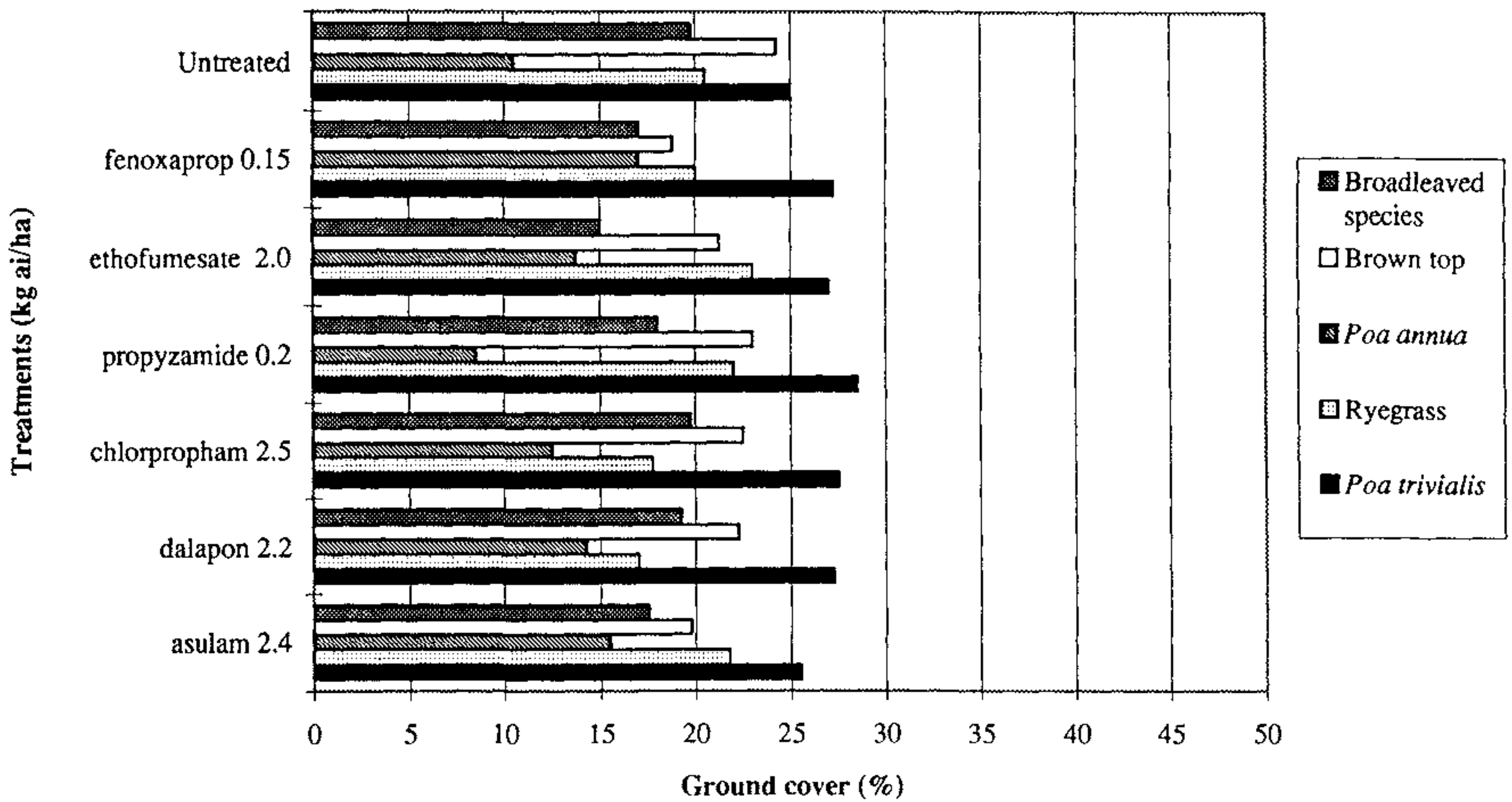
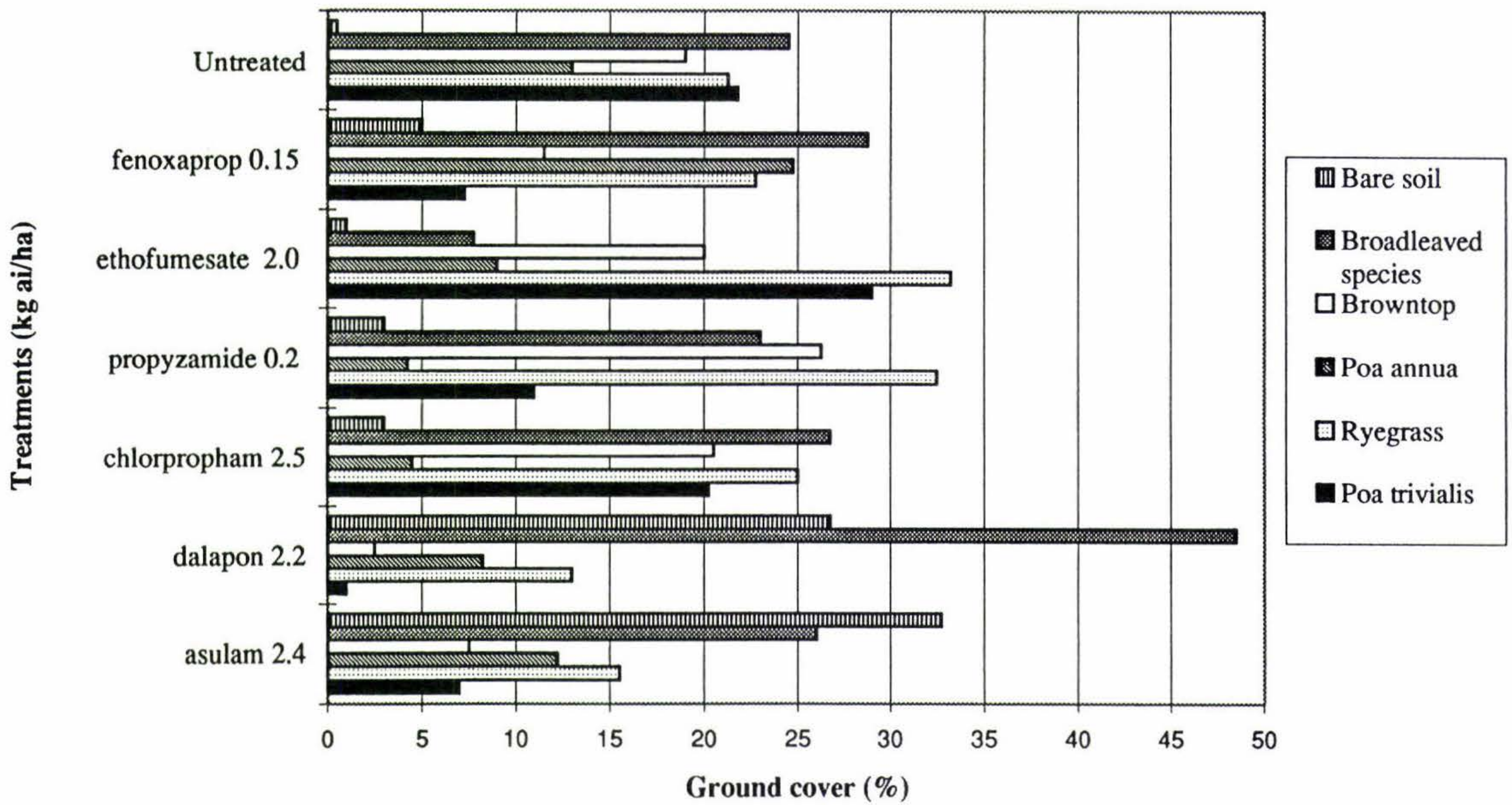


Figure 4.4: The average ground cover (%) in plots on 18 November 1995 (6 weeks after spraying).



Bare soil made up a large proportion (25% or more) of the dalapon and asulam treated plots, 6 weeks after spraying (Plate 4.8). This was due to the significant reductions in *Poa trivialis* and browntop in these plots. All other treatments resulted in a small proportion (less than 5%) of bare soil to be exposed in the plots.

Plate 4.8: Field plot 6 weeks after treatment with dalapon.

4.3 TRIAL 3 (SECOND SCREENING POT TRIAL)

4.3.1 *Poa trivialis* pots (visual damage scores)

Three weeks following spraying, the isoproturon/diflufenican treatment at the highest rate caused more damage to the *Poa trivialis* plants than all other treatments (Table 4.4). Visually the plants treated with isoproturon/diflufenican mixture appeared scorched, burnt off at the leaf tips, with some dead tillers.

Six weeks following spraying, the dalapon treatments had the highest damage scores. Both rates of dalapon caused significant (P=0.05) damage to *Poa trivialis* compared with the untreated control. Visual symptoms of herbicide damage appeared as yellowing leaves followed by necrosis. Adding MCPA or picloram/triclopyr mix to fenoxaprop caused no significant damage to *Poa trivialis* compared with the untreated control. Fenoxaprop applied without the addition of broadleaved herbicides caused significant damage to *Poa trivialis* compared with the untreated control. Visual symptoms of fenoxaprop damage on the plants appeared as paleness and reddening of leaves followed by some necrosis (refer Plate 4.9).

Twelve weeks following spraying all dalapon, asulam, propyzamide and fenoxaprop treatments with the exclusion of MCPA or picloram/triclopyr mix had caused significant (P=0.05) damage compared with the untreated control. All plants in these treatments appeared dead or close to death at the time of assessment.

Table 4.4: The effect of herbicides 3, 6 and 12 weeks after being applied to transplanted *Poa trivialis* plants in pots on 19 October 1995.

Treatment	kg ai/ha	Time of assessment		
		Week 3	Week 6	Week 12
asulam	2.0	3.8 cde	5.3 bcde	8.0 a
asulam	4.0	2.8 cde	7.3 abc	10 a
dalapon	3.0	4.8 ab	8.3 a	10 a
dalapon	4.4	4.5 bc	8.0 ab	10 a
ethofumesate	3.0	2.3 de	3.0 ef	5.0 b
fenoxaprop	0.15	2.6 de	6.8 abcd	8.5 a
fenoxaprop + oil	0.15	2.8 cde	4.5 cdef	8.0 a
fenoxaprop + oil	0.30	4.0 bcd	5.5 abcde	8.5 a
fenoxaprop + oil	0.60	3.3 bcde	7.3 abc	8.5 a
fenoxaprop +	0.15	2.3 de	2.3 f	3.8 b
picloram	0.20			
triclopyr	0.60			
fenoxaprop +	0.15	2.8 cde	3.5 ef	3.5 b
MCPA	1.5			
isoproturon + diflufenican	2.0 + 0.4	3.3 bcde	3.5 ef	4.0 b
isoproturon + diflufenican	3.0 + 0.6	6.5 a	8.0 ab	9.0 a
propyzamide	0.20	2.5 de	4.3 def	8.3 a
propyzamide	0.40	2.5 de	5.3 bcde	10 a
thifensulfuron-methyl	0.03	2.3 de	3.5 ef	3.5 b
trinexapac-ethyl	0.75	2.0 e	3.5 ef	3.5 b
untreated		2.3 de	3.5 ef	3.8 b

- Means within a column followed by the same letter are not significantly different at the 5% level.

Plate 4.9: *Poa trivialis* 6 weeks after treatment with fenoxaprop.

Score 9

4.3.2 Perennial ryegrass pots (visual damage scores)

Three weeks following spraying, the highest isoproturon/diflufenican treatment caused significantly (P= 0.05) more damage to perennial ryegrass plants than other treatments (Table 4.5). Visually leaves appeared scorched, dying, flattened, limp and brown in colour.

Six weeks following spraying, the asulam and isoproturon/diflufenican treatments damage scores were significantly (P= 0.05) higher than all other treatments. Visual symptoms of isoproturon/diflufenican damage appeared as necrosis of leaves (Plate 4.10). Asulam treatments were seen as twisting, distortion, and yellowing of the tillers (Plate 4.11). All other treatments except for the highest rate of fenoxaprop (with the addition of D-C trate) were not significantly different compared with the untreated control. Signs of a nitrogen deficiency were evident in many treatments with yellowing of tillers and loss of vigour. A slow release granule nitrogen fertiliser was applied..

Twelve weeks following spraying, isoproturon/diflufenican at the highest application rate showed significantly (P = 0.05) more damage to perennial ryegrass plants than all other treatments. Plants in this treatment appeared dead or close to death at the time of assessment. Asulam, dalapon, fenoxaprop and propyzamide treatments that had showed significant differences from the untreated control in earlier weeks had all recovered and were showing no signs of herbicide damage.

Table 4.5: The effect of herbicides 3, 6 and 12 weeks after being applied to transplanted perennial ryegrass plants in pots on 19 October 1995.

Treatment	kg ai/ha	Time of assessment		
		Week 3	Week 6	Week 12
asulam	2.0	4.3 bcd	6.0 bc	1.3 b
asulam	4.0	4.0 bcde	7.3 ab	2.3 b
dalapon	3.0	4.0 bcde	3.8 de	1.2 b
dalapon	4.4	5.3 bc	3.3 de	1.3 b
ethofumesate	3.0	2.0 ef	2.8 e	1.3 b
fenoxaprop	0.15	4.0 bcde	3.8 de	1.5 b
fenoxaprop + oil	0.15	4.5 bcd	3.5 de	1.0 b
fenoxaprop + oil	0.30	3.5 cdef	3.0 e	1.3 b
fenoxaprop + oil	0.60	4.5 bcd	5.0 cd	1.3 b
fenoxaprop +	0.15	3.0 def	3.5 de	1.3 b
picloram	0.20			
triclopyr	0.60			
fenoxaprop +	0.15	4.0 bcde	3.0 e	1.0 b
MCPA	1.5			
isoproturon + diflufenican	2.0 + 0.4	6.0 b	5.0 cd	1.0 b
isoproturon + diflufenican	3.0 + 0.6	8.3 a	8.5 a	8.0 a
propyzamide	0.20	4.5 bcd	3.5 de	1.3 b
propyzamide	0.40	3.3 cdef	3.3 de	1.3 b
thifensulfuron-methyl	0.03	3.3 cdef	3.3 de	1.0 b
trinexapac-ethyl	0.75	3.5 cdef	4.0 de	1.5 b
untreated		1.5 f	2.8 e	1.0 b

- Means within a column followed by the same letter are not significantly different at the 5% level.

Plate 4.10: Perennial ryegrass 6 weeks after treatment with the control to the left (score 2) and isoproturon to the right (score 10).

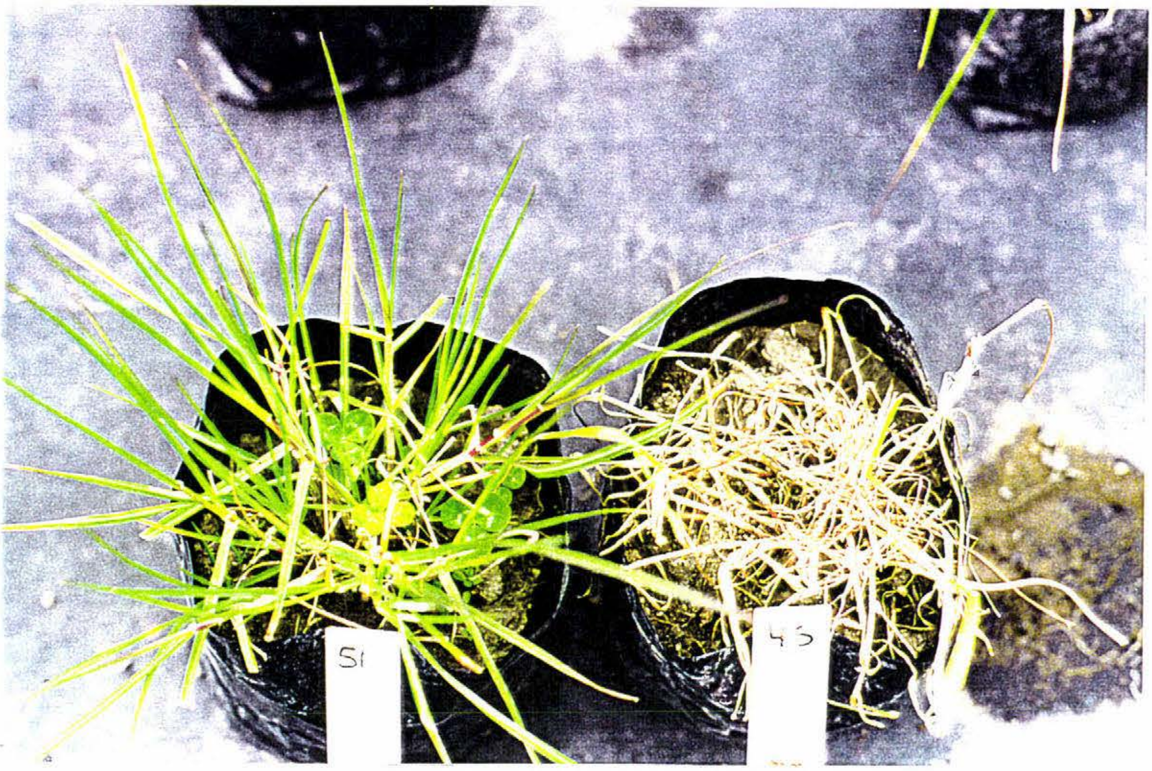


Plate 4.11: Perennial ryegrass 6 weeks after treatment with asulam

Score 5

4.3.3 Shoot fresh weights

The fresh weights of both *Poa trivialis* (Figure 4.5) and perennial ryegrass (Figure 4.6) gave similar results to those obtained by visual scoring prior to harvesting the shoots.

In the *Poa trivialis* pot trial, all treatments had lower fresh weights when compared with the untreated control. However, fenoxaprop with the addition of the broadleaved herbicides and the growth regulator, trinexapac-ethyl, showed no significant (P = 0.05) difference in *Poa trivialis* fresh weights compared with the untreated control.

In the perennial ryegrass pot trial, the isoproturon/difluefenican treatment at the highest rate caused a significant (P = 0.05) reduction in fresh weight compared to the untreated control. All other herbicide treatments were not significantly different from the untreated control in shoot fresh weights.

Figure 4.5: The average fresh weight of *Poa trivialis* shoots harvested from pots on the 14 January 1996, 16 weeks after application of the herbicides.

Bars to the left of the graph join treatments which are not significantly different at P = 0.05.

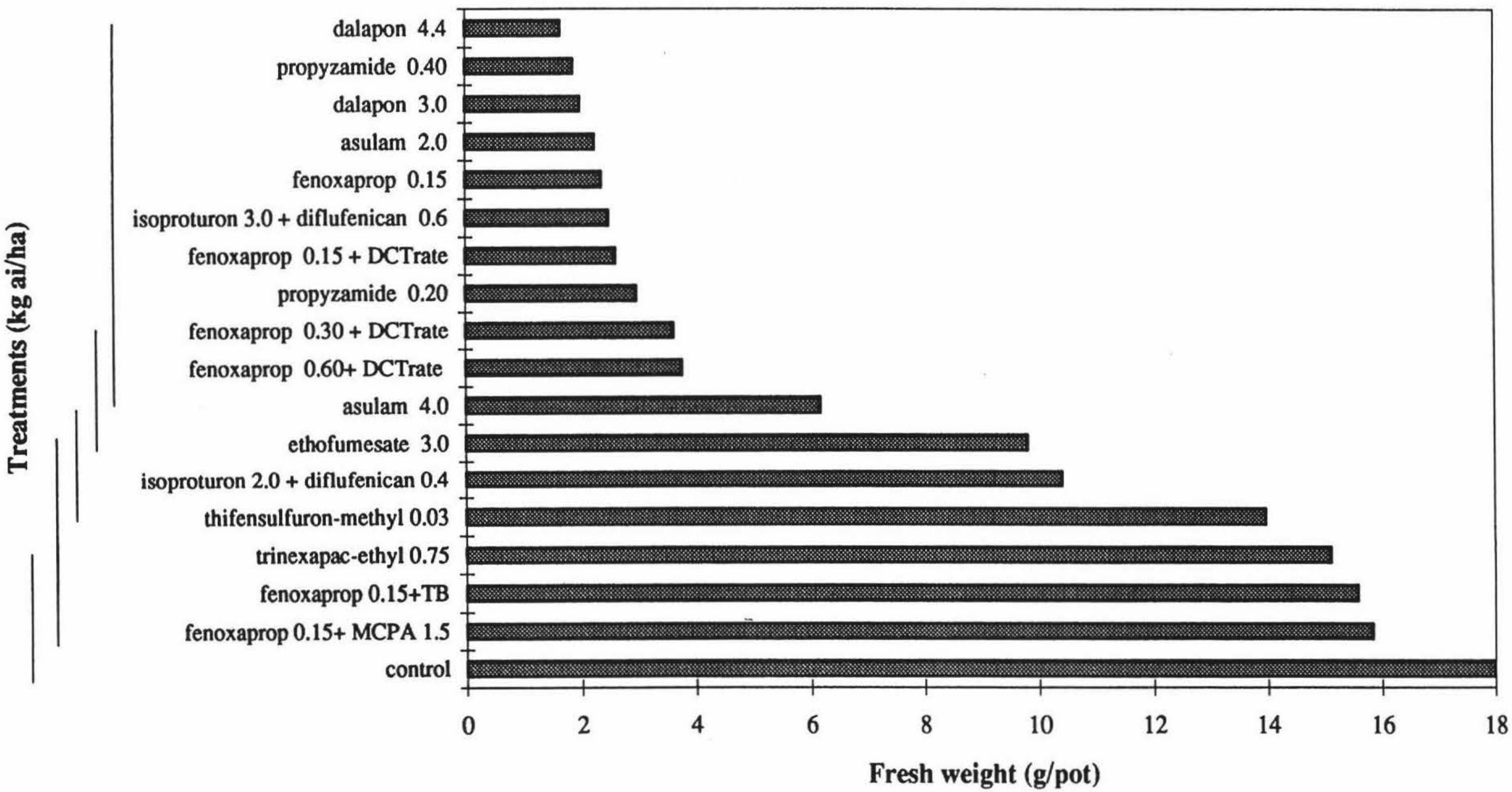
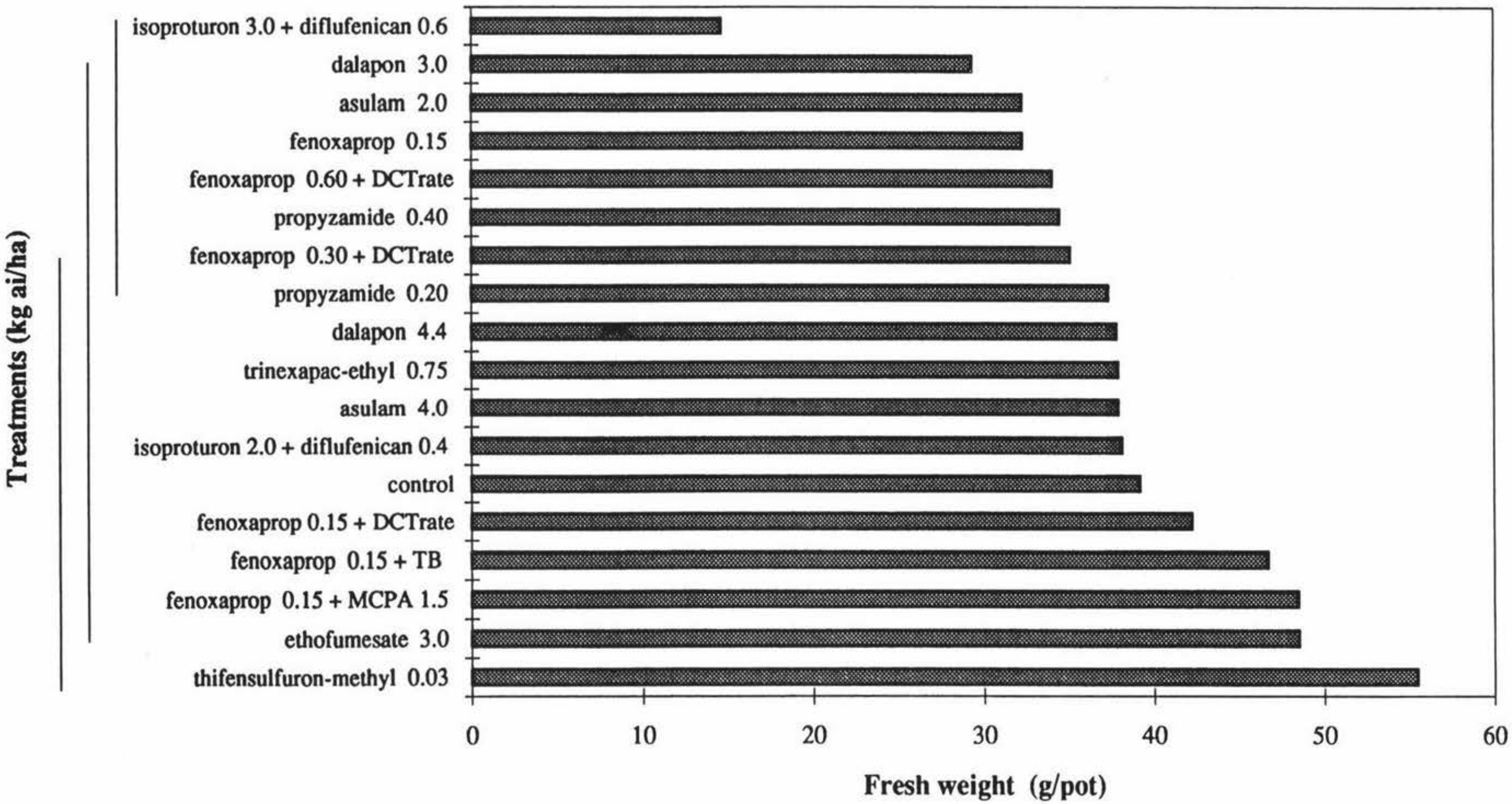


Figure 4.6: The average fresh weight of perennial ryegrass shoots harvested from pots on 14 January 1996, 16 weeks after application of the herbicides.

Bars to the left of the graph join treatments which are not significantly different at P = 0.05.



4.4 TRIAL 4 (RESIDUE PERSISTENCE BIOASSAY)

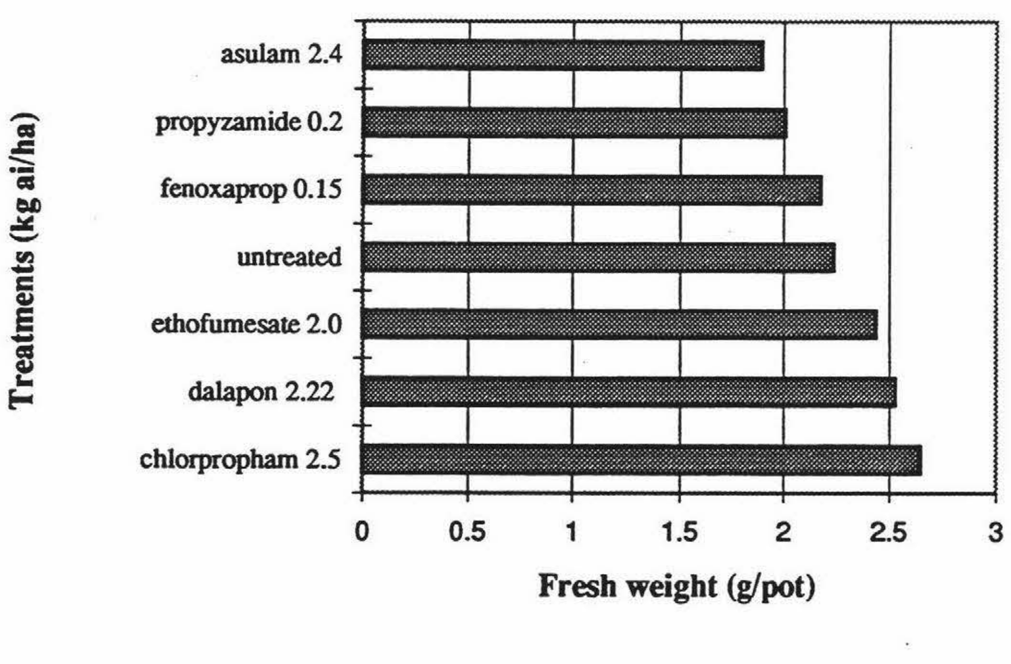
4.4.1 Plant counts

Perennial ryegrass seedlings emerged on the 2 November 1995, 7 days after planting. Counts of perennial ryegrass seedlings at this stage showed no significant (P = 0.05) difference between perennial ryegrass numbers in each treatment. All seedlings appeared healthy with no signs of herbicide residues affecting germination.

4.4.2 Shoot fresh weights

At the time of harvest on 1 December 1995 there was no significant difference (P = 0.05) in perennial ryegrass average shoot fresh weights between any of the treatments (Figure 4.7).

Figure 4.7: The average shoot fresh weights of perennial ryegrass plants at harvest 1 December 1995, 5 weeks after sowing the seed.



5. DISCUSSION

As stated in Chapter 1, the underlying aim of this study was to determine which chemicals, if any, may be used to effectively remove *Poa trivialis* from a racetrack sward without harming perennial ryegrass. The susceptibility of *Poa trivialis* and perennial ryegrass to herbicides was examined in three pot trials and one field trial. In this chapter, the results of all four experiments are considered together. The effectiveness of each herbicide will be discussed, as will the timing, requirement for undersowing and relative chemical costs.

5.1 Effectiveness of the herbicides

5.1.1 Ethofumesate

Ethofumesate was evaluated in all trials. It caused no significant damage ($P = 0.05$) to *Poa trivialis* in either pot trial or field trial and had no residual effect on the germination of perennial ryegrass seed sown 3 weeks after spraying. In the field trial, ethofumesate reduced *Poa annua* content by 40% or more in treated plots as expected (Ball & Roberts 1974; Glasgow 1991). However, the most obvious effect was the complete removal of white clover from treated plots. This was not unexpected either as Hare & Rolston (1990) had found ethofumesate was particularly damaging to white clover in lotus seed crops.

According to Mead *et al* (1974), Haggar & Bastian (1976) and Brock & Henderson (1980), the chemical works best in winter during cool wet conditions. This evidence is supported by Anon (1993), who found the effectiveness of ethofumesate was reduced by warm temperatures or if the soil was too dry. Sufficient rain fell over the period of the trials to prevent the soil from becoming too dry (see Appendix 2). However, soil temperatures throughout the trial period varied considerably. In the first pot trial, which began in July, the average soil temperature was 6.8 ^{0}C for the month. In the field trial and second pot trial, which began in October, the average soil temperature was 12.9 ^{0}C for the month. Higher soil temperatures experienced in late spring may have reduced the effectiveness of ethofumesate to control *Poa trivialis*. However, poor control was still achieved when applied in the middle of winter.

5.1.2 Carbamates

Asulam was evaluated in all trials. It caused no significant damage to *Poa trivialis* in the first pot trial. However, at higher rates (2.0-4.0 kg/ha) it caused significant damage to the species in the second pot trial. In the field trial, asulam was applied at 2.4 kg/ha, 50% higher than recommended by O'Connor (1994) to control docks in pastures. In asulam treated plots, *Poa trivialis* and *Poa annua* content were reduced by 70% and 50% respectively although a 30% reduction in perennial ryegrass was also measured 6 weeks after spraying.

These asulam trial results support work carried out by Oswald *et al* (1972) on pastures. They confirm that high doses of asulam are effective in suppressing *Poa trivialis* in a perennial ryegrass sward. However satisfactory control of *Poa trivialis* is achieved with a severe initial check to perennial ryegrass in the sward.

The other carbamate tested was chlorpropham. The herbicide applied at a rate of 2.5 kg/ha caused no significant damage to *Poa trivialis* in the first trial and only partial suppression to the species in the field trial. Therefore, as suggested by Mueller-Warrant and Brewster (1986), the herbicide is unlikely to provide satisfactory control of *Poa trivialis* in a perennial ryegrass sward.

Neither carbamate caused any residual effect on the germination of perennial ryegrass seed sown 3 weeks after spraying. The residual activity of asulam may have been reduced by leaching of the chemical through the soil post spraying. According to Fryer & Makepeace (1977), asulam has a high solubility (5000 ppm) compared with chlorpropham which has a lower solubility (89 ppm).

5.1.3 Dalapon

Dalapon was used in all the trials. In the first pot trial, dalapon caused some damage to *Poa trivialis* when applied at 1.5 kg/ha a rate recommended by O'Connor (1994) for safety in perennial ryegrass pastures. The addition of TCA did not improve the effectiveness of dalapon for controlling established *Poa trivialis*. In the second pot trial, dalapon was applied at two higher rates *i.e.* 3.0 and 4.0 kg/ha. Complete kill of *Poa trivialis* was achieved at both these rates with no long term adverse effects to perennial ryegrass.

In the field trial, dalapon was applied at 2.2 kg/ha as recommended by Mueller & Brewster (1986). There was satisfactory control of *Poa trivialis* (90% reduction) although this was masked to a certain extent by the degree of phytotoxicity caused to perennial ryegrass and the re-invasion of bare spaces, particularly by broadleaved species such a yarrow and white clover.

The use of sequential applications of dalapon at a lower rate (*i.e.* 1.5 kg/ha) may allow for the gradual conversion of a *Poa trivialis* infested racetrack sward back to dominance by perennial ryegrass. This should result in minimal surface disruption of the turf without the dramatic loss of turf or ingress of weeds such as white clover and yarrow. The ideal time to apply sequential applications of dalapon would be in autumn. The herbicide could suppress the competitive ability of *Poa trivialis* through the winter allowing perennial ryegrass to compete and re-establish as the dominant species during early spring. Further field trial work is required to evaluate such an effect.

5.1.4 Fenoxaprop

Fenoxaprop applied at 0.15 kg/ha was the only herbicide to cause significant (P= 0.05) damage to *Poa trivialis* in first pot trial. Furthermore, fenoxaprop caused no adverse effects to perennial ryegrass in this trial.

In the field trial, fenoxaprop was applied at the same rate as used in the first pot trial, but this time D-C-Trate was added to improve efficacy. Fenoxaprop reduced *Poa trivialis* content substantially by over 75% without any adverse effect to the perennial ryegrass. However, it had no effect on other major weeds species present *i.e. Poa annua* or white clover, and many *Poa annua* plants were flowering, 6 weeks after fenoxaprop was applied.

In the second pot trial, fenoxaprop was applied at a number of different rates to determine the optimum application rate for controlling *Poa trivialis* selectively in perennial ryegrass swards and to investigate the effect on fenoxaprop activity of adding D-C-Trate and herbicides for broad-leaved weed control. Results showed that the activity of fenoxaprop on *Poa trivialis* was not improved by increasing the application rate above 0.15 kg/ha or by adding D-C-Trate. Results also confirmed O'Connor's (1994) recommendation that fenoxaprop should not be mixed with herbicides being used to control broad-leaved weeds. The performance of fenoxaprop was reduced substantially by the presence of either MCPA or the picloram/triclopyr mix in the fenoxaprop spray solution.

In conclusion, fenoxaprop applied at a rate of 0.15 kg/ha will reduce the *Poa trivialis* content substantially in an established sward without causing any harm to perennial ryegrass. However, it will not provide control of *Poa annua* and white clover. Both these species are undesirable weeds on racetracks. *Poa annua* is un-wanted because it is shallow rooting and able to regenerate from seed at any time of the year, whereas white clover is undesirable as it makes the ground slippery which can cause a horse to slip and fall when galloping on the racetrack .

5.1.5 Propyzamide

Propyzamide was applied in all trials. In first pot trial, propyzamide was applied at 0.1 kg/ha, but this caused no significant (P = 0.05) damage to either *Poa trivialis* or perennial ryegrass at this rate. In the field trial, propyzamide was applied at double the first trial rate (0.2 kg/ha) to improve its efficacy on *Poa trivialis*. Results showed a 50% reduction of *Poa trivialis* and *Poa annua* density without any adverse effect on perennial ryegrass, browntop and white clover. In the second pot trial, propyzamide was applied at 0.2 and 0.4 kg/ha. Complete kill of *Poa trivialis* was achieved at the higher rate, and plants were only 20% the size of the untreated plants at the lower rate. These results agree with work by Paxman & Forgie (1972) who found propyzamide applied at a rate of 0.3 kg/ha gave 90 to 100% control of *Poa trivialis* with little damage to perennial ryegrass in pastures.

According to O'Connor (1994) propyzamide may adversely affect the germination of perennial ryegrass up to three months after spraying. However, from the residual bioassay it was found that propyzamide applied at 0.2 kg/ha in the field trial had no significant effect on the germination of perennial ryegrass seed sown 3 weeks after spraying. According to Walker (1970) there is little loss of herbicidal activity following application of propyzamide when the soil temperatures remain below 13 ^{0}C but under warmer conditions loss is rapid (half life 2-4 weeks). Also, Walker (1970) discovered that the rate of propyzamide residue loss was retarded when the surface soil becomes dry. In the field trial, sufficient rain fell over the period, average soil temperature for the week following spraying was 15.4 °C and for the month of October 12.9 °C. Therefore, the breakdown of propyzamide in the soil would appear to be very temperature and moisture dependent. If propyzamide was applied in mid autumn a similar soil residue persistence would be expected, due to similar soil temperatures experienced at this time of the year.

There appears to be a safe rate and time of application of propyzamide to achieve selective control of *Poa trivialis* in a perennial ryegrass sward. Rates in excess of 0.4 kg/ha are likely to be too severe on perennial ryegrass. However, a rate of 0.2 to 0.3 kg/ha applied in late spring would seem to be acceptable.

5.1.6 Ureas

In both pot trials, none of the sulfonyl ureas or substituted ureas tested showed much potential for selectively controlling mature *Poa trivialis* in a perennial ryegrass sward. Therefore as a consequence none of these herbicides were used in the field trial. Most of the documented research done with the success of these chemicals had been conducted on *Poa annua* (Henderson & Brock, 1976; Harvey, 1985; Rolston & Hare, 1986), with best results achieved for *Poa trivialis* as seedlings rather than as mature plants (Mueller-Warrant & Brewster 1986; Anon 1994a).

5.1.7 Isoproturon + diflufenican mixture

Isoproturon/diflufenican at a rate of 2.0 and 0.4 kg/ha respectively showed poor selectivity when applied post-emergence, temporarily checking the growth of both species. In the second pot trial a 50% higher rate was also tested which caused severe damage to both grass species. According to Wooley (1992) the herbicide may give variable selectivity when applied at post-emergence compared with pre-emergence control. This statement is supported from these trial results.

5.1.8 Triazines

In the first pot trial, atrazine and prometryn were applied at rates of 2.0 and 1.0 kg/ha respectively. Neither herbicide caused any significant ($P = 0.05$) damage to *Poa trivialis* so were not considered for further evaluation. According to Muzik (1975) low soil temperatures (5-10 ^{0}C) as experienced in the first pot trial, following treatment may delay the expression of symptoms and in most cases decrease the phytotoxicity of the triazines. Therefore, if the triazines were applied in the second pot trial enhanced phytotoxicity may have been expected at the above rates. Also Mueller-Warrant & Brewster (1986) claimed both herbicides are more likely to be effective on *Poa trivialis* at the seedling stage rather than in an established sward.

5.1.9 Others

Other chemicals tested such as mecoprop, dicamba, triclopyr and pendimethalin in the first trial caused no significant ($P = 0.05$) damage to *Poa trivialis*. These results were not unexpected as all of these herbicides except for pendimethalin are more commonly used to control broadleaved weeds rather than grasses. However work by Birnie (1984) and Harvey (1985) had found these herbicides at high rates to control *Poa trivialis* at the seedling stage in a mature perennial ryegrass sward.

5.2 Timing of herbicide application

Aberg & Stecko (1975) claimed that the control of perennial weeds is most effective when herbicides are applied to plants or parts of plants when either rapidly growing or have been weakened by rapid growth which has temporarily depleted or exhausted their reserves. The interpretation of this statement suggest that *Poa trivialis* plants are most susceptible to herbicide damage in the germinaton or young seedling stage. However, in a racetrack sward *Poa trivialis* plants are normally already established and survive as perennial weeds going through a cessation phase in summer and rejuvenating from stolons in the autumn. Therefore, the most susceptible time to apply a herbicide is suspected to be autumn when the new shoots are still in a young stage and have consumed the greater part of the reserve nutrients in the stolon system. In this study, all trial work was carried out on established actively growing *Poa trivialis* plants so they could be easily identified in the field and for transplanting into pots. If the herbicides had been applied in the autumn rather than the spring better results would have been expected due to the increased susceptibility of the plant at the re-growth stage.

5.3 Why and when to undersow

One of the facts of turf agronomy, and an unfortunate one so far as recolonisation after spraying is concerned is that perennial ryegrass is tufted in growth habit. The grass species is relatively immobile and can only spread vegetatively by means of tiller production on the periphery of the area inhabited. In contrast broadleaved weeds such as white clover and yarrow are creeping in nature therefore capable of ramifying extensively over vacant ground so as to provide herbage cover in a short period of time. Shoots and roots can arise from nodes still connected to the plant material which may be some distance away and provide them with aggressive ability to extend their area from low initial presence to high status after spraying. The ingress of weeds after spraying suggest an important role for undersowing in the process of recolonisation.

According to Beard (1973) the best time to undersow is just prior to an anticipated period of optimum soil temperatures and moisture. Seedlings grown under favourable conditions in a racetrack sward have an opportunity to make the greatest amount of growth and are better able to survive the unfavourable conditions that may subsequently occur. Ormsby (1995) claimed that sowing in the middle of autumn is preferable to late spring when the field trial was carried out. The reasons being; the duration of favourable soil temperature is much longer, rainfall is generally more consistent, less disease pressure, and competition from weeds is much greater in spring than autumn. The exception to the above is where warm season species are to be established, in which case spring/early summer sowing is essential.

Having undersown the racetrack, emphasis should then focus on providing an environment that will allow a dense turf cover to be established in the shortest possible time. Areas requiring attention will include cultural factors such as irrigation, fertilisation and mowing as mention in Section 2.5.

5.4 Cost of the herbicides

It is well accepted that the presence of *Poa trivialis* in a racetrack sward creates a poor racing surface (Field & Murphy 1987; Fleming 1994). This is due to the grass species having a shallow root system that is easily dislodged from the soil surface. However, the effect of a *Poa trivialis* infested race track in terms of economic cost is difficult to quantify.

According to Williams (1994) a poor racing surface leads to inconsistent horse performance, injury to horses, poorer quality horses racing, smaller field sizes and possible abandonment of meetings in adverse weather. The outcome is an overall drop in the standard of racing and a decrease betting turnover. To equate in dollar terms, the loss of a top line galloper through injury may cost the industry in the vicinity of $100,000. The abandonment of a meeting due to the inability of the racing surface to cope with adverse weather could cost in the vicinity of $150,000 dollars per meeting. For the club and the industry this equates to a significant loss in revenue. According to Williams (1994) this can lead to a viscous circle developing, where a club receiving less income puts less back into the track surface, with a corresponding decrease in track performance.

The relative costs of the various herbicides used in the field trial are presented in Table 5.1 and have been calculated as chemical cost per hectare which does not include spraying application costs. The area required to spray will vary between racetracks as they are not all of the same size. The course size at the Awapuni racetrack is approximately 5 hectares.

Table 5.1: Price per hectare for application of herbicides assessed in the field trial (Source Oliver & Burtt 1995).

HERBICIDE		RATE	PRICE
Active ingredient	Trade name	Kg (ai/ha)	($/ha)
dalapon	Chemagro Dalapon	2.2	30
propyzamide	Kerb Flo	0.20	40
asulam	Asulox	2.4	180
chlorpropham	Chloro IPC	2.5	190
fenoxaprop	Puma S	0.15	210
ethofumesate	Nortron 500 SC	2.0	450

From Table 5.1 the least expensive herbicides used in the field trial were dalapon and propyzamide. Although dalapon caused unacceptable damage to perennial ryegrass at 2.2 kg/ha, a lower rate of 1.5 kg/ha applied in three sequential applications several weeks apart as suggested earlier (Section 5.1.3) would still make the cost of the chemical comparatively cheap (approximately $70/ha). The additional time and labour required to spray the track three times would make the herbicide as expensive to apply as fenoxaprop though.

Propyzamide is a cheap herbicide at $40/ha. The chemical was safe to use on perennial ryegrass and substantially reduced the *Poa trivialis* content in the sward. According to O'Connor (1994) the herbicide will also control some broadleaved weeds such as chickweed. The Compositae family (e.g. yarrow) is resistant to the herbicide though.

The most expensive herbicide applied in the field was ethofumesate at over $400/ha. Furthermore, this chemical had no effect on *Poa trivialis,* and so cannot be recommended for control of *Poa trivialis* on racetracks.

6. CONCLUSIONS

An integrated management strategy will be required to control *Poa trivialis* on New Zealand racetracks. There is no one herbicide from these trials that will completely remove *Poa trivialis* without damaging perennial ryegrass in a racetrack sward. Also there is little use in attempting to convert a turf sward to perennial ryegrass dominance using chemicals unless the cultural factors responsible for the increased presence of *Poa trivialis* are not corrected. If edaphic factors such as drainage and aeration are corrected the swing to perennial ryegrass dominance may occur spontaneously. The only advantage of using herbicides then would be to stimulate the process or try to completely eradicate the problem. Control of *Poa trivialis* on racetracks in the future will require racecourse managers to develop an integrated approach that incorporates both cultural control techniques and chemical control.

Cultural control techniques will involve regular remedial work such as vertidraining or vibra-moling the racetrack to improve drainage and aeration, the use of light weight machinery and a movable running rail to reduce compaction. A change in management philosophy (as discussed in Section 2.5) with respect to mowing, fertiliser and irrigation strategies will be required to reduce the *Poa trivialis* content in the race track and to keep the level low.

Chemical control will involve developing a herbicide programme that has a strong emphasis on safety to perennial ryegrass in the racetrack sward. Only those herbicides that showed minimal damage to perennial ryegrass should be used. The use of herbicides that cause variable or harmful effects to perennial ryegrass such as dalapon or asulam at higher rates than suggested for pastures in the field trial should be avoided. However, the opportunity does exist to apply these chemicals at lower rates, in sequential applications several weeks apart, which may allow for the gradual conversion of the *Poa trivialis* infested racetrack back to the desirable perennial ryegrass sward. Further research is required in this area.

The safest herbicides assessed in the field trial on perennial ryegrass were ethofumesate, propyzamide, fenoxaprop and chlorpropham. However, of these four herbicides tested, damage to *Poa trivialis* was only significant in the fenoxaprop and propyzamide treatments. Poor control of *Poa trivialis* was achieved with ethofumesate, while only partial suppression was achieved by chlorpropham, indicating that neither of these treatments are likely to control established *Poa trivialis* plants at rates required for safety to perennial ryegrass.

Propyzamide and fenoxaprop applied in the field trial at rates of 0.2 kg/ha and 0.15 kg/ha respectively, showed good promise for reducing the *Poa trivialis* content substantially in late spring with minimal injury to perennial ryegrass in an established sward. Propyzamide is the preferred option as the herbicide is less expensive to buy and can provide some control of *Poa annua* in the perennial ryegrass sward.

If spraying with propyzamide is to be carried out a considerable proportion of the sward should be perennial ryegrass otherwise undersowing will be required. The aim of undersowing is to both reduce the loss of turf cover caused by the disappearance of *Poa trivialis* and reduce the ingress of weed species growing in the racetrack sward. From the residual bioassay propyzamide at a rate of 0.2 kg/ha will not affect the germination of perennial ryegrass seed sown 3 weeks after spraying in late spring

Future investigations should be conducted with propyzamide at rates of 0.2-0.3 kg/ha in autumn. This is the suggested time of the year when the *Poa trivialis* plants are most susceptible to herbicide damage i.e. immediately after regrowth from old stolons in an established perennial ryegrass sward. The degree to which *Poa trivialis* might recover and require retreatment in subsequent seasons will also need measuring.

It is impossible to eliminate a species as competitive and resourceful as *Poa trivialis*. However, there are enough tools and knowledge available to allow racetrack managers to reduce this species to one that is a minor component of turf on New Zealand racetracks.

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8. APPENDIX 1

Soil Analysis Laboratory Report

Name: Philip Fleming	**Sample Type:** Soil Pasture
Address: Plant Science Massey University	**Date :** 17/5/95

ANALYSIS		LEVEL FOUND	NORMAL RANGE *
ph		5.6	5.8 - 6.5
Phosphorous	**(ug/ml)**	12	15 -30
Potassium	**(me/100g)**	0.33	0.50 - 0.80
Calcium	**(me/100g)**	9.0	6.0 - 12.0
Magnesium	**(me/100g)**	1.13	1.00 - 3.00
Sodium	**(me/100g)**	0.10	0.20 -0.50
CEC	**(me/100g)**	21	12.0 - 25.0
Bulk density	**(g/ml)**	1.13	0.60 -1.00

*** Normal range was obtained from the Analytical services laboratory for soil pasture.**

Source : Fertiliser & Lime Research Centre, Massey University
Palmerston North.

9. APPENDIX 2

Weather Information collected from the weather station located at Grasslands AgResearch, Palmerston North. The weather station is approximately 3km from the field trial (Awapuni racetrack) and 200m from the pot trial site (Massey University Plant Growth Unit).

Table A 2.1 Trial 1: weather conditions for day of spraying (14 July 1995) and the week following spraying.

Date	14/7/95	15/7/95	16/7/95	17/7/95	18/7/95	19/7/95	20/7/95	21/7/95
Rainfall (mm)	5.8	0.6	6.3	-	0.3	12.4	16.5	6.6
Soil temperature to 10cm depth (°C)	9.8	9.0	8.0	5.8	3.4	5.0	7.0	6.7
Air temperature (°C)	11.0	7.9	7.7	5.4	1.2	5.5	9.0	8.6

Figure A 2.1 Trial 1: total weekly rainfall for Palmerston North one week before spraying and five weeks after spraying on 14 July 1995.

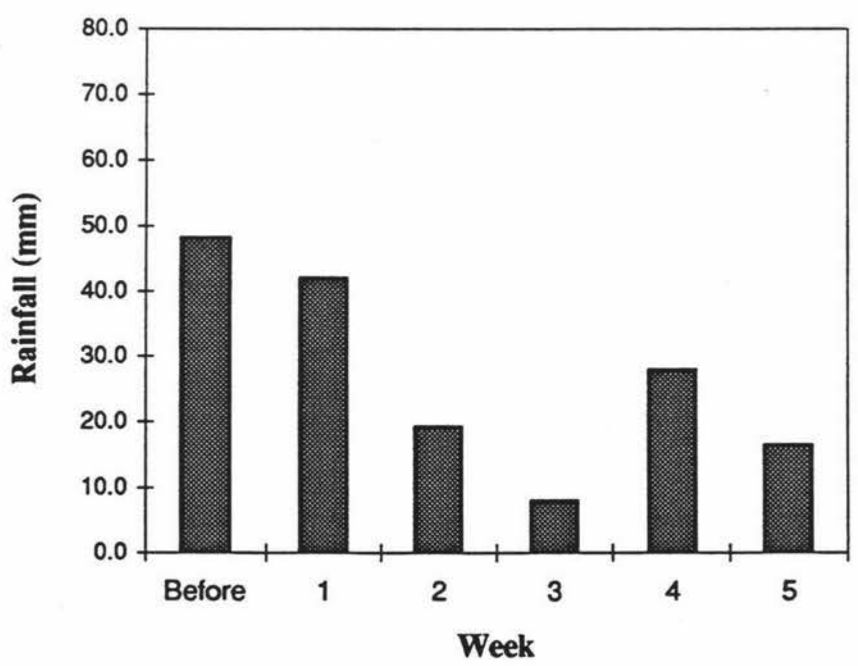

Table A 2.2 Field Trial: weather conditions on day of spraying (3 October 1995) and the week following spraying.

Date	3/10/95	4/10/95	5/10/95	6/10/95	7/10/95	8/10/95	9/10/95	10/10/95
Rainfall (mm)	none	3.3	20.5	3.6	0.9	3.7	40.4	5.5
Soil temperature to 10cm depth (°C)	13.5	14.0	14.1	13.0	13.9	13.3	13.6	12.3
Air temperature (°C)	13.6	11.6	15.1	11.5	12.0	12.8	13.6	8.4

Figure A 2.2 Field trial: total weekly rainfall for Palmerston North one week before spraying and five weeks after spraying on 3 October 1995.

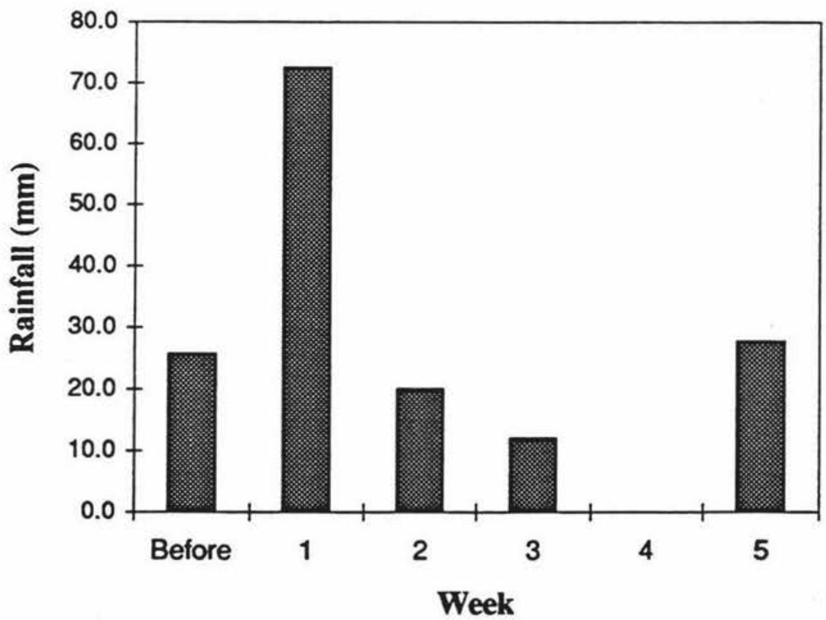

Table A 2.3 Trial 3: weather conditions on day of spraying (19 October 1995) and the week following spraying.

Date	19/10/95	20/10/95	21/10/95	22/10/95	23/10/95	24/10/95	25/10/95	26/10/95
Rainfall (mm)	3.1	0.1	6.9	-	-	-	-	-
Soil temperature to 10cm depth (°C)	11.9	10.1	12.4	10.9	12.4	12.7	13.6	14.4
Air temperature (°C)	11.9	9.6	10.7	10.7	12.1	13.4	13.8	14.3

Figure A 2.3 Trial 3: total weekly rainfall for Palmerston North one week before spraying and five weeks after spraying on 19 October 1995.

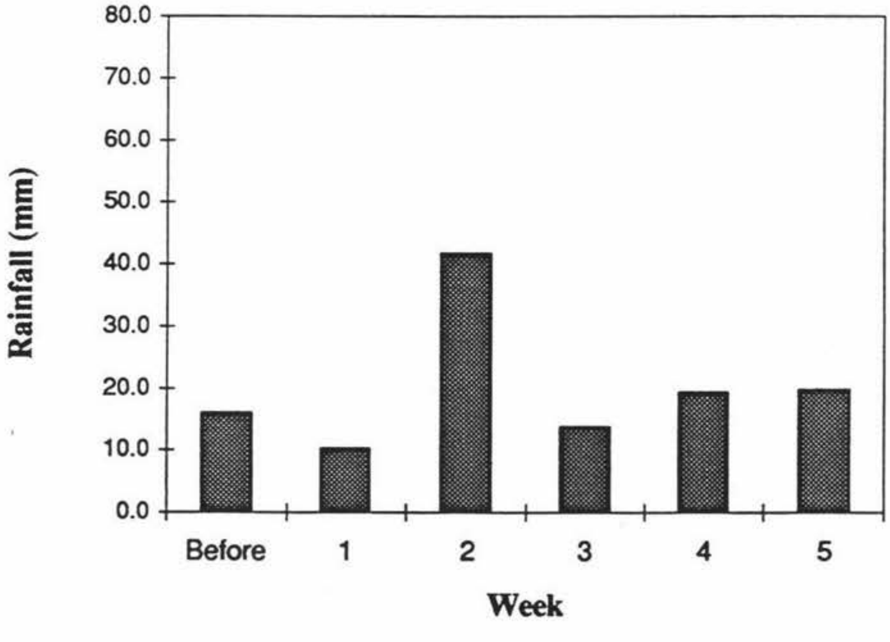

Figure A 2. 4 The average daily air temperature in Palmerston North over the trial periods from July to December 1995

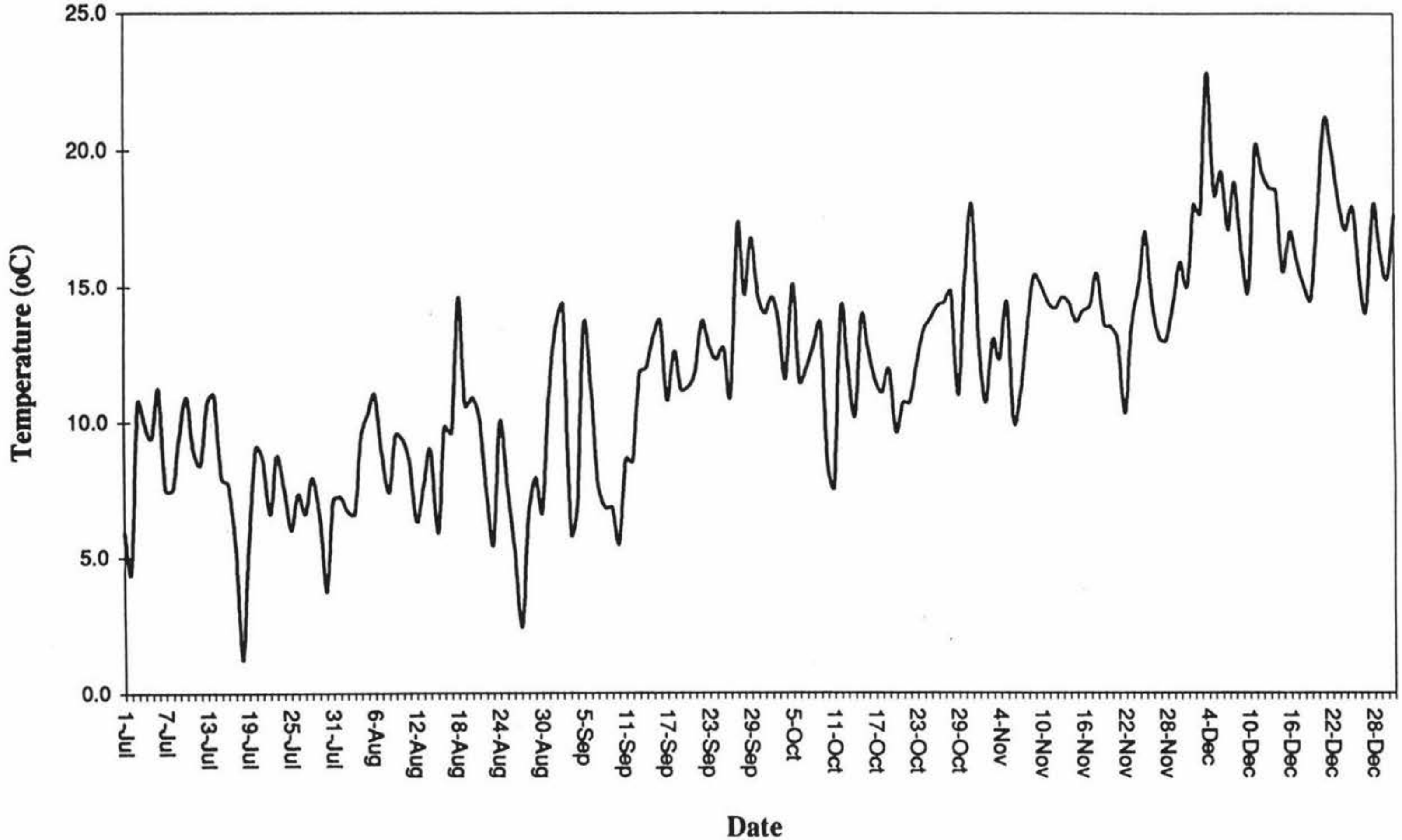

Figure A2.5 The average daily soil temperature in Palmerston North over the trial periods from July to December 1995.