Tolerance to herbicides of ground cover species for New Zealand orchards

K.C. Harrington[A] and A. Rahman[B]
[A]Department of Plant Science, Massey University, Palmerston North, New Zealand.
[B]AgResearch, Ruakura Research Centre, Private Bag 3123, Hamilton, New Zealand.

Summary

A potential strategy for orchard floor management in New Zealand is to grow ground covers which suppress weeds during the growing season, then to apply herbicides to selectively remove any weeds which do establish, spraying only during crop dormancy to minimize the risk of herbicide contamination of fruit.

Herbicide tolerance studies were conducted on eight plant species with potential for ground cover use. *Festuca rubra* and *F. longifolia* tolerated a wide range of grass-killing herbicides and could be easily cleared of weeds. Weeds in *Trifolium repens* could be controlled by haloxyfop, 2,4-D, MCPA and glyphosate, while paraquat, diquat, simazine and haloxyfop could be used in *Lotus pedunculatus* swards. *Dichondra micrantha* was sufficiently tolerant of tribenuron, clopyralid, glyphosate, glufosinate and paraquat/diquat to make it a suitable candidate for use in orchards. *Hydrocotyle heteromeria* and *Centella uniflora* tolerated several knock-down herbicides and also warrant consideration as ground cover species. However, the range of herbicides tolerated by dryland bent *Agrostis castellana* would not allow easy removal of grass weeds. The potential for using ground covers in orchards for weed control is discussed.

Introduction

Throughout the world, consumers are demanding that food contains little or no pesticide residues. Present weed control practices for fruit production in New Zealand rely on herbicides to keep the soil bare within tree rows, while vegetation between the rows is mowed (Harrington *et al.* 1992). As bare soil provides a favourable environment for establishment of weeds, residual herbicides or several applications of foliar-applied knockdown herbicides are necessary throughout the growing season. Herbicide applications made during the active growing period of the trees increases the risk of chemical residues being deposited on or within the developing fruit.

At present there are few alternatives to herbicides for minimizing weed competition under orchard trees. Mulches are generally too expensive and mowing to the base of trees without damaging trees or irrigation equipment can be difficult. Repeated cultivation destroys soil structure and damages crop roots. Grazing animals (such as sheep) damage fruit on low-growing branches, and training trees with high branches increases picking costs. Attempts to grow ground cover plants without the use of herbicides generally results in invasion by more competitive weed species (Mantinger and Gasser 1987).

If herbicides are used to remove weeds in ground covers while fruit trees are dormant, competition under fruit trees could be reduced with minimal risk of herbicide residues in fruit. The smothering ability of ground cover species may keep more competitive weed species from establishing during the growing season. Herbicides could then be used between growing seasons to remove any weeds that establish.

Donaldson *et al.* (1988) used selective herbicides between growing seasons in vineyards to encourage low-growing weed species, thus preventing more competitive weeds from establishing in spring. However, another approach could be to plant the orchard floor with a ground cover species tolerant of broad-spectrum herbicides, allowing removal of weeds between growing seasons.

Previous studies have identified five ground cover species which tolerate a wide range of herbicides (Harrington 1993, Harrington and Grant 1993), making them worthy of further assessment under field conditions. This paper presents results from herbicide investigations that were conducted on a further eight plant species. The objective was to identify more potential ground cover species worth including in a field assessment. Low growing perennial species were needed which tolerate a wide range of herbicides.

Materials and methods

Between 1993 and 1996, the tolerance of the eight ground cover species (Table 1) to herbicides was tested in a series of 11 experiments (Table 2). These were all pot experiments apart from Experiment 10 which used turf plots of well established hydrocotyle. The three grass (dryland bent, hard fescue and creeping red fescue) and two legume species (white clover and lotus) were established from commercially available seeds. Other species (dichondra, hydrocotyle and centella) were established in pots by transplanting vegetative material collected from field sites near Palmerston North. Plants were grown in 600 mL polythene planter bags, except in Experiment 11 which used 1.5 L bags. The potting medium used for all pot experiments was a Kiwitea loam soil (pH 5.0, organic carbon 4.5%).

Plants in Experiments 1–9 were maintained in a heated glasshouse where the temperature was kept above 10°C. Pots were positioned on felt mats kept damp from beneath by automatic irrigation. Pots for Experiment 11 were kept outdoors on a sheltered sub-irrigated sand-bed. Herbicides were not applied until all plants were well established (3–12 months after transplanting or sowing of plants) (Table 2). A completely randomized experimental design was used for species which established uniformly in all bags (Experiments 4, 6, 7, and 9). A randomized block design was used for the remaining experiments where species showed uneven establishment.

Herbicide treatments were applied to pots using a modified version of the pendulum laboratory sprayer described by Wiese (1977). Plants were placed below the pivotal centre of a swinging boom and

Table 1. Species assessed for herbicide tolerance.

Family name	Botanical name	Common name	Cultivar name
Apiaceae	*Centella uniflora* (Col.)Nannf.	centella	
Apiaceae	*Hydrocotyle heteromeria* A.Rich.	hydrocotyle	
Convolvulaceae	*Dichondra micrantha* Urban	dichondra	
Fabaceae	*Lotus pedunculatus* Cav.	lotus	'Grasslands Maku'
Fabaceae	*Trifolium repens* L.	white clover	'Grasslands Tahora'
Poaceae	*Agrostis castellana* Boiss. & Reut.	dryland bent	'Milford'
Poaceae	*Festuca longifolia* Thuill.	hard fescue	'Serra'
Poaceae	*Festuca rubra* L.	creeping red fescue	'Grasslands Tasman'

herbicide was forced through two flat fan nozzles by compressed air. The boom was released from the same height for each application. To calibrate the sprayer, a sheet of glass placed below the boom was weighed following application. Spraying volumes and number of herbicide treatments for each experiment are listed in Table 2. Herbicides and application rates are listed with the results (Tables 3–8). Generally the lowest rates that would be expected to provide useful weed control within an orchard were selected. No adjuvants were added unless label recommendations strongly recommended their inclusion (mineral oil to clethodim in Experiments 4–6). Each herbicide treatment was replicated five times except for Experiments 1 and 2 which had six replicates. Each experiment also had a replicated untreated control.

Pots received overhead irrigation 24 hours after spraying to wash herbicides into the soil. The average air temperature for the 7 week period following application is shown in Table 2 for each experiment.

The field plots in Experiment 10 each measured 5 × 3 m, and were composed of poor quality grass turf and well-established hydrocotyle. Plots were heavily shaded by nearby trees and were mowed once every two weeks. The soil was a Karapoti brown sandy loam. A randomized block design with three replicates was used, and treatments were applied with a precision propane-powered plot sprayer.

The extent of herbicide damage to ground cover species in all experiments was scored at regular intervals after treatment using a linear scale from 0 (no noticeable effects of herbicide) through to 10 (plant totally dead). The extent of chlorosis, necrosis, distortion, stunting and other symptoms of herbicide damage were considered when allocating intermediate scores. Note that untreated plants were often not allocated a score of zero if they showed signs of chlorosis or stunting caused by such stresses as nutrient deficiencies which were difficult to differentiate from mild herbicide damage. An analysis of variance was conducted on the arcsine transformed data, and means were separated using the Student-Newman-Keuls multiple range test.

Table 2. Summary of experiments to assess herbicide tolerance of ground cover species.

Expt	Species	Date sprayed	Number of treatments	Spray volume (L ha^{-1})	Plant age (months) when sprayed	Mean air temp (°C) for next 7 weeks
1	lotus	Feb 1993	12	333	3	20.5
2	white clover	Feb 1993	15	333	3	20.5
3	hydrocotyle	Feb 1993	19	310	3	19.7
4	creeping red fescue	Apr 1993	19	318	5	15.8
5	hard fescue	Apr 1993	18	318	5	15.8
6	dryland bent	Apr 1993	18	318	5	15.8
7	centella	Dec 1993	18	301	12	21.7
8	dichondra	Jan 1994	18	308	12	22.1
9	hydrocotyle	Jun 1994	5	350	5	13.0
10	hydrocotyle	May 1995	6	250	>12	8.8
11	dichondra	Feb 1996	18	256	4	15.5

Table 3. Damage scores for three grass species assessed 7 weeks after application in Experiments 4–6 (0=no damage, 10=dead). Mean values with asterisks are significantly different from the untreated control (P=0.05).

Treatment	Application rate (kg a.i. ha^{-1})	Dryland bent	Creeping red fescue	Hard fescue
amitrole	1.6	7.0*	–	–
asulam	1.6	7.0*	1.6	1.5
clethodim[A]	0.08	8.0*	1.4	1.5
clethodim[A]	0.17	–	1.4	3.2
clopyralid	0.30	0.2	1.6	0.0
fluazifop	0.31	9.0*	1.6	0.6
fluazifop	0.62	9.0*	1.0	1.5
glyphosate	0.54	8.6*	4.6*	1.8
haloxyfop	0.12	8.8*	0.8	0.6
haloxyfop	0.25	–	1.6	0.4
MCPA	1.5	1.6	1.0	0.9
MCPA + clopyralid	1.5 + 0.3	1.4	1.7	0.6
oxadiazon	1.6	5.0*	–	–
paraquat + diquat	0.36 + 0.18	9.0*	5.8*	6.8*
pendimethalin	1.65	5.0*	1.6	1.4
quizalofop	0.11	9.0*	1.0	0.6
quizalofop	0.21	–	1.4	0.8
sethoxydim	0.4	8.8*	1.2	0.4
sethoxydim	0.8	8.8*	1.0	0.4
sethoxydim	1.2	–	1.4	–
tribenuron	0.015	0.2	1.4	1.0
tribenuron	0.030	0.8	–	–
untreated	–	0.9	1.4	1.2

[A] Clethodim was applied with a mineral oil adjuvant (2 L ha^{-1} D-C-Trate).

Results and discussion

Because of the large number of treatments used and the numerous data sets collected (scores at several intervals), only one representative set of scores for each experiment is shown (Tables 3–8). Data from 6–8 weeks after application gave the best relative ranking of the damage sustained, and hence indicated which herbicides were better tolerated by the test species. For some herbicides with rapid action (such as paraquat and oxadiazon), early scorching sometimes occurred, but this is not apparent in the results presented. Recovery from this initial scorching 6–8 weeks after application indicated that such herbicides could be useful in managing a ground cover sward by controlling weeds which were susceptible to this early scorching.

Grass species

The two fine fescue species were assessed in these experiments due to the reported tolerance of creeping red fescue to aryloxyphenoxypropionate (AOPP) and cyclohexanedione (CHD) herbicides (Lichtenthaler *et al.* 1989). The tolerance of 5-month-old plants of both fescues in Experiments 4 and 5 to clethodim, fluazifop, haloxyfop, quizalofop and sethoxydim (Table 3) has confirmed this earlier work. These relatively low growing grasses will make very suitable ground cover species. Taller grass weeds can be selectively removed using any of these herbicides, and any broad-leaved species can be chemically removed with such herbicides as MCPA and clopyralid.

Dryland bent was also assessed as it is low-growing and has some tolerance of the sulfonylurea herbicides. This is shown by the low scores for tribenuron (Table 3). However poor tolerance (scores above 7.0) of the AOPP and CHD herbicides suggests that grass weed control may be difficult in swards of dryland bent. The fescues also appeared to be more tolerant of pendimethalin and low rates of glyphosate compared to dryland bent, making fine fescues appear much more versatile with regard to weed control. Subsequent trial work also indicates that of these three grasses, dryland bent is the more susceptible to drought stress (data not presented).

Legumes

White clover has been assessed as a ground cover species in orchards in previous investigations (Stinchcombe and Stott 1983), and considerable information exists on the tolerance of this species to herbicides (Rolston 1987). Lotus is now being used extensively in New Zealand as a ground cover species in forests. Experiments 1 and 2 were designed to confirm previous work and obtain further information to assist with the management of these legume swards in orchards.

Table 4. Damage scores for two legume species assessed 7 weeks after application in Experiments 1 and 2 (0=no damage, 10=dead). Mean values with asterisks are significantly different from the untreated control (P=0.05).

Treatment	Application rate (kg a.i. ha^{-1})	Lotus	White clover
clopyralid	0.2	7.8*	–
2,4-D (amine salt)	1.0	8.7*	0.1
2,4-DB	2.4	7.2*	–
dichlobenil	6.1	0.5	2.7*
glufosinate	0.8	9.5*	–
glyphosate	0.36	–	0.3
glyphosate	0.72	7.8*	4.7*
glyphosate	1.44	–	6.0*
MCPA	1.1	–	0.8
norflurazon	2.4	–	0.4
oryzalin	3.0	0.0	0.0
oxadiazon	1.6	–	0.0
oxyfluorfen	0.72	–	0.9
paraquat + diquat	0.24 + 0.12	0.0	6.5*
paraquat + diquat	0.48 + 0.24	0.0	7.6*
paraquat + diquat	0.72 + 0.36	–	9.0*
pendimethalin	1.6	0.1	0.0
simazine	1.0	0.0	–
simazine	1.5	–	3.1*
simazine	2.0	0.2	–
untreated	–	0.0	0.0

Table 5. Damage scores for three prostrate stoloniferous ground cover species assessed 7 weeks after application in Experiments 3, 7 and 8 (0=no damage, 10=dead). Mean values with asterisks are significantly different from the untreated control (P=0.05).

Treatment	Application rate (kg a.i. ha^{-1})	Hydrocotyle	Centella	Dichondra
amitrole	1.6	0.6	2.7	–
amitrole	2.4	–	–	10.0*
amitrole	3.2	0.7	6.5*	–
asulam	1.6	7.0*	9.7*	8.4*
clopyralid	0.22	4.2	2.1	2.0
clopyralid	0.45	6.5*	1.6	–
2,4-D (amine)	1.1	1.0	4.8	8.3*
dalapon	5.1	0.2	2.8	5.0
diuron	1.6	9.9*	–	–
diuron	2.4	–	–	4.4
diuron +linuron	0.74 + 1.1	–	–	3.1
glufosinate	0.6	1.4	0.7	0.9
glyphosate	0.54	3.7	2.1	1.8
haloxyfop	0.25	1.1	0.6	1.6
MCPA	1.1	2.5	4.2	5.8
norflurazon	2.4	0.1	1.3	4.8
oryzalin	3.5	2.8	0.5	0.8
oxadiazon	1.6	0.9	0.8	2.1
oxyfluorfen	0.72	1.6	1.0	1.3
paraquat + diquat	0.24 +0.12	0.1	5.5*	1.3
simazine	1.5	8.9*	2.5	4.9
tribenuron	0.015	1.5	0.4	0.6
untreated	–	0.9	1.2	0.8

Although MCPA and 2,4-D damage to white clover is considered undesirable in pastures (Rolston 1987), well established plants are seldom killed. The good recovery of treated plants by 7 weeks after application (Table 4) shows that these two herbicides may be useful for controlling broad-leaved weeds in pure clover swards. Reduced growth rates are unlikely to cause problems in an orchard unless the sward opens enough to allow ingress of more weeds.

These results (Table 4) confirm that white clover is tolerant to low rates of paraquat and glyphosate (Rolston 1987). The paraquat/diquat mixture was more damaging than expected, presumably due to the young age (3 months old) of the plants at spraying. The damage caused by this paraquat/diquat mixture was even more severe 2 weeks after treatment, but some recovery had occurred in plants scored 7 weeks after spraying. Although better established plants would probably tolerate these herbicides more successfully, application rates would need to be kept low to prevent severe opening of the canopy. However it is unlikely that low rates of glyphosate or paraquat would effectively remove perennial weed species.

The tolerance of white clover to a number of residual herbicides (dichlobenil, norflurazon, oryzalin, oxadiazon, oxyfluorfen, pendimethalin and simazine) was also assessed (Table 4). If the clover canopy is damaged when trying to remove weeds, application of a residual herbicide may prevent new weeds from establishing while the canopy is recovering. White clover showed excellent tolerance (never any symptoms of herbicide damage) of pendimethalin and oryzalin, and acceptable tolerance (some initial but only temporary damage) of oxadiazon, norflurazon, oxyfluorfen, dichlobenil and simazine. To minimize the risk of herbicide residues entering fruit, a white clover sward could be used to suppress weeds in the orchard during the growing season, and herbicides such as haloxyfop, 2,4-D, MCPA or glyphosate could be applied in late autumn to remove weeds which have invaded the sward. Should the sward become damaged by these applications, a herbicide with a relatively short residual life, such as oryzalin or pendimethalin, could then be applied. Residues of these herbicides should have dissipated completely before the fruit begin forming in the following season.

Although lotus and white clover are both legume species, their tolerance of some herbicides differed significantly. Lotus was much less susceptible to the paraquat/diquat mixture than white clover. The initial scorch suffered by lotus was less severe than for white clover, and no damage could be detected in lotus at the 7 week assessment (Table 4). Lotus was also less affected by dichlobenil or simazine than white clover. These results agree with the findings of Hare and Rolston (1986), who recommended winter applications of paraquat and simazine for removing weeds from lotus seed crops.

Lotus appeared to be as tolerant as white clover to oryzalin and pendimethalin. However it was much more susceptible than white clover to 2,4-D, and also appeared less tolerant of glyphosate.

Although not tested, lotus should tolerate AOPP herbicides such as haloxyfop, allowing grass weeds to be selectively removed. Thus use of haloxyfop, paraquat/diquat, simazine, dichlobenil, oryzalin and pendimethalin should allow selective removal of many weed species from a lotus sward. However, the safety of these herbicides would need testing under field conditions first, especially if mixtures of these herbicides were used. None of these herbicides would control perennial broad-leaved species very well. Paraquat would probably be the most useful of these herbicides, but dependence on this chemical may be unacceptable to many orchardists because of its high mammalian toxicity.

Table 6. Damage scores (0=no damage, 10=dead) for hydrocotyle growing in pots for Experiment 9. Mean values with asterisks are significantly different from the untreated control (P=0.05).

Treatment	Application rate (kg a.i. ha^{-1})	After 6 weeks	After 3 months
amitrole	1.6	4.6*	4.4
amitrole	3.2	6.2*	10.0*
oxadiazon	1.5	1.2	1.8
amitrole + oxadiazon	1.6 + 1.5	5.8*	8.2*
amitrole + oxadiazon	3.2 + 1.5	6.2*	10.0*
untreated	–	1.2	2.0

Table 7. Damage scores (0=no damage, 10=dead) for hydrocotyle growing in field plots for Experiment 10. Mean values shown with asterisks are significantly different from the untreated control (P=0.05).

Treatment	Application rate (kg a.i. ha^{-1})	After 6 weeks	After 10 weeks
clopyralid	0.21	1.0	1.7
dicamba	0.30	1.3	1.3
ethofumesate	2.0	1.0	2.3
glufosinate	1.0	10.0*	10.0*
mecoprop-P	1.6	8.3*	10.0*
tribenuron	0.011	3.3	2.0
untreated	–	1.3	4.0

Table 8. Damage scores for dichondra assessed 8 weeks after application in Experiment 11 (0=no damage, 10=dead). Mean values with asterisks are significantly different from the untreated control (P=0.05).

Treatment	Application rate (kg .i. ha^{-1})	Score after 8 weeks
chlorsulfuron	0.015	2.6
chlorsulfuron	0.030	2.8
clopyralid	0.22	3.2
clopyralid	0.45	3.2
dicamba	0.20	3.0
diuron	1.2	3.0
diuron	2.4	2.0
glyphosate	0.54	3.2
mecoprop-P	0.90	4.6*
oryzalin	3.5	3.4
oryzalin + oxadiazon	3.5 + 1.5	3.4
oxadiazon	1.5	3.0
paraquat + diquat	0.25 + 0.15	2.4
paraquat + diquat	0.50 + 0.30	2.4
pendimethalin	1.6	2.8
tribenuron	0.015	3.2
tribenuron	0.030	3.0
triclopyr	1.2	8.0*
untreated	–	2.8

Hydrocotyle

Many species of *Hydrocotyle* form dense mats in turf, and are often tolerant of turf herbicides (Matthews 1975). One of the most troublesome weeds in New Zealand lawns is *Hydrocotyle heteromeria* (Harrington 1990), which is the species assessed in Experiments 3, 9 and 10. The shade tolerance of this species makes it a good candidate to use under orchard trees, although it may not survive under dry conditions.

Results from the first experiment indicated hydrocotyle could tolerate haloxyfop, amitrole, tribenuron, 2,4-D, dalapon, and probably also low rates of a paraquat/diquat mixture, glufosinate, MCPA, and glyphosate (Table 5). Norflurazon, oxadiazon and oxyfluorfen are residual herbicides potentially useful for weed management in swards of hydrocotyle in orchards.

The potential to use amitrole and oxadiazon was investigated further in Experiment 9. The tolerance of hydrocotyle to oxadiazon was confirmed, but there was less tolerance of low rates of amitrole in the June experiment compared to when tested in February. Increasing the rate of amitrole or applying it with oxadiazon caused significant damage.

Experiment 10 investigated the safety of several herbicides to field plots of hydrocotyle in winter. This experiment confirmed the safety for hydrocotyle of tribenuron and low rates of clopyralid. It also identified dicamba and ethofumesate as herbicides suitable for use in hydrocotyle swards. All four of these herbicides selectively removed white clover successfully, which was a weed in these plots.

Centella

Centella is another low-growing mat-forming weed species from the Apiaceae family that was studied. It did not appear to be as tolerant of amitrole, 2,4-D or a paraquat/diquat mixture as hydrocotyle (Table 5). However it showed useful tolerance levels for haloxyfop, tribenuron, clopyralid, glufosinate, oxadiazon, oryzalin, oxyfluorfen, norflurazon and low rates of glyphosate. The range of herbicides available indicates that centella also has good potential as a ground cover species in orchards with respect to ease of weed control.

Dichondra

Dichondra is an amenity ground cover species which has been popular as a lawn substitute in southern California and other parts of the world (MacCaskey 1982). Some herbicide tolerance information is available, albeit mainly for herbicides that are no longer available in New Zealand. Matthews (1975) recommended diuron and bensulide for weed control in dichondra, while Elmore *et al.* (1972) found oryzalin and nitrofen to be safe. Williams (1974) showed that monuron, napropamide, noruron and dichlobenil were well tolerated.

The results from Experiment 8 showed dichondra can also tolerate haloxyfop, tribenuron, clopyralid and possibly low rates of glyphosate, glufosinate or a paraquat/diquat mixture (Table 5). The glyphosate, glufosinate and paraquat/diquat treatments caused severe initial damage, but the plants had recovered well by the 7 week assessment. Recovery may have taken longer if treatment had not occurred during active summer growth, and use of these herbicides while trees are dormant in winter may not be possible. Oryzalin and oxadiazon appear to be safe residual herbicides for preventing weed ingress following damage to the cover caused by other herbicides. In New Zealand, diuron is recommended to control weeds in dichondra swards, but in this experiment, it caused considerable damage to plants. Oxyfluorfen caused severe initial scorching, but the plants recovered well.

Results from Experiment 11 (Table 8) confirmed many of the results from Experiment 8. Recovery from the paraquat/diquat mixtures was again rapid despite severe damage initially. However, diuron caused no damage to dichondra in the second experiment, and dicamba appeared to be tolerated well. The tolerance to tribenuron in the first experiment was shown again in Experiment 11 at twice the rate. There was also very good tolerance of chlorsulfuron. As well as tolerating a wide range of herbicides, dichondra would be suitable as a ground cover in orchards because of the dense low growing mats of vegetation that it forms.

Concluding discussion

This series of experiments was conducted to identify ground cover species that can tolerate a sufficiently wide range of herbicides to allow weeds which establish to be selectively removed. The results presented indicate that many of the species we studied do tolerate a number of herbicides, and would be suitable for further assessment under field conditions. The species showing most potential are creeping red fescue, hard fescue, white clover, dichondra and hydrocotyle, although centella and lotus are also worth further consideration.

Label recommendations regarding the weed species controlled by the herbicides found to be safe suggest that many of the weeds likely to invade these ground cover species could be selectively removed within an orchard. The ground covers could be used to smother weeds during the growing season and any weeds which do establish could be removed selectively once orchard fruit has been harvested, thus minimizing the risk of herbicide contamination.

Although many of the herbicides investigated are presently registered for use in orchards, a number of them are not (2,4-D, 2,4-DB, ethofumesate, MCPA, mecoprop-P, tribenuron). If these were used during tree dormancy, there would be little risk of damage to trees or residues contaminating fruit. However, since these are not legally registered currently for use in orchards, this limits the range of herbicides that can be used.

Further work is necessary to determine how to successfully establish such swards since the herbicide screenings of this research were conducted on well established plants rather than seedlings. Herbicide tolerance studies under field conditions in winter are also needed, and the safety to ground covers of herbicide mixtures and sequential application of chemicals needs investigation. The experiments reported here were designed mainly to identify promising herbicide-tolerant ground cover species. They were not to provide definitive herbicide recommendations for weed control purposes.

Although a number of potentially useful ground cover species have been identified which are not traditional grass or legume species, seed production techniques for some of these alternative species must be developed before they can be used by growers. Without a ready supply of affordable seed, orchardists are unlikely to grow these species. Some are stoloniferous species with seeds produced at ground level, which could make seed harvesting difficult.

These swards must also tolerate orchard conditions, for example, dryness in summer, shading (especially when covered in leaves in autumn) and compaction from passing machinery. Should they need to be mown, the appropriate intensity and frequency of defoliation will need to be determined. The effect of the ground covers on the quantity and quality of fruit produced by trees also needs studying.

Problems with seed availability and lack of information on management requirements of hydrocotyle and centella may make grasses and clovers more desirable as ground covers. However, even low-growing grass species may need regular mowing to prevent them competing with trees. Likewise, white clover has reduced yields from young fruit trees when left unmanaged (Hartley 1988). Legumes may also be undesirable because nitrogen fixation may cause vigour problems in fruit trees by providing too much nitrogen. They act as alternate hosts for insect pests over the winter period after trees have shed their leaves (Burnip and Suckling 1997).

In 1993, trials commenced in an apple orchard to assess hard fescue, white clover, hydrocotyle, dichondra, cotula (*Leptinella dioica*) and pearlwort (*Sagina procumbens*) as ground covers under field conditions (Harrington 1995). Information presented in this paper has been used to control weeds each winter since the trial was established. Many of the issues raised above are being addressed with this field trial.

While our research has concentrated on use of ground covers in orchards, the concepts could be equally useful for providing vegetation control in other situations, such as in amenity areas where heavy use of residual herbicides may no longer be acceptable.

Conclusion

If long-term single-species ground covers are to be used in orchards, it must be possible to remove weeds which establish using herbicides. Work reported in this paper shows that a number of ground cover species exist which will tolerate a good range of herbicides. Field studies are now needed, and have begun, to determine whether these ground covers will be useful for integrated weed management in orchards.

Acknowledgments

Financial assistance for this study was provided by the Foundation for Research, Science and Technology.

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