Ethofumesate and Frost Tolerance of *Lotus pedunculatus*, White Clover and Cocksfoot

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ABSTRACT

Ethofumesate is widely used for weed control in lotus (*Lotus pedunculatus* Cav. syn *uliginosus* Sch) and cocksfoot (*Dactylis glomerata* L.) seed crops. It is particularly important in selectively controlling volunteer white clover in lotus. Maximum activity of ethofumesate occurs in winter and can be enhanced by frost, often causing severe herbicidal effects on lotus.

To further study this interaction, a controlled environment experiment investigated the effects of frost severity, duration and timing relative to herbicide application to seedling and mature plants of lotus, white clover (*Trifolium repens* L.) and cocksfoot. Plants were subsequently grown on in the field to seed harvest.

Enhancement of ethofumesate activity by increasing frost severity was confirmed. The number of sequential frosts or their timing in relation to herbicide application had no effect. Cocksfoot proved tolerant of ethofumesate despite considerable frost damage. Lotus was moderately tolerant, recovering rapidly once herbicidal activity had ceased so that subsequent summer seed yields were not affected. White clover was not killed by ethofumesate at 3 kg ai ha^{-1} and although plants recovered, vigour and seed yield in summer were greatly reduced.

When selecting ethofumesate application rates in winter, some allowance should be made for possible uncharacteristic frost events outside that normally expected. The role of plant competition for control of white clover in lotus is emphasised.

Additional index words: seed production, maturity.

INTRODUCTION

The herbicide ethofumesate has shown promise for the control of volunteer white clover (*Trifolium repens* L.) in 'Grasslands Maku' lotus (*Lotus pedunculatus* Cav.) seed crops (Brock and Henderson 1976), and has been used in commercial seed crops (Neal, 1983). Cold temperatures enhance the activity of ethofumesate (O'Connor et al., 1975), and in some instances it has been noted ethofumesate injury to lotus was increased when frost occurred near the time of application.

Ethofumesate is also used for annual grass weed control (eg. *Poa annua*) in some perennial grass seed crops such as ryegrass (*Lolium* spp) and cocksfoot (*Dactylis glomerata* L.) (Rolston and Hare, 1986), although the tolerance of cocksfoot is lower than of ryegrass (Lee, 1977). A trial at Gore showed the regrowth of 'Grasslands Wana' cocksfoot was injured by frost whereas other cocksfoot cultivars were not (J.D. Turner, pers. comm.).

Ethofumesate may be of widespread use in winter spray programs in seed crops such as lotus and cocksfoot, a series of trials were initiated to investigate aspects of ethofumesate activity and frost using controlled environments.

Seed crops can be established in both autumn (in warmer northern regions), and spring (in cooler southern regions), therefore winter application of ethofumesate would be to either seedling or established crops. It has also been observed that lotus herbage produced early in autumn is often sensitive to early out-of-season frosts, herbage produced later developing better frost hardiness. Thus, crops growing in the warmer northern areas may be more frost sensitive.

The two experiments reported in this paper studied the reactions of seedling and mature plants of lotus, white clover, and cocksfoot to combinations of ethofumesate applications and frost conditions, when grown at a range of temperatures typical of winter conditions encountered in the main seed growing areas of New Zealand. The effects were followed through to seed harvest.

MATERIALS AND METHODS

The study covered an 18 month period and was divided into two sections. The first section covering pretreatment establishment and controlled environment treatments was conducted in the Climate Laboratory at Plant Physiology Division, DSIR, Palmerston North, with the second section assessing treatment effects on subsequent growth and seed production carried out in the field at Grasslands Division, DSIR, Palmerston North.

Experimental design and treatment

In order to accommodate the large array of treatments to be investigated, but fit within the Controlled Environment (CE) rooms of the Climate Laboratory, a pot trial employing a one-third replicated 3^5 factorial de

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sign was used. Total number of pots required was 243 or 81 per CE room. The following treatments were used.

A. Plant species (Sp): 1) 'Grasslands Maku' lotus, 2) 'Grasslands Huia' white clover, and 3) 'Grasslands Wana' cocksfoot.
B. Growth temperatures (GT) of CE rooms ($\pm$ 0.5C): 1) 16/9C (day/night), 13/6C, and 10/3C.
C. Ethofumesate herbicide (HR): 1) Nil, 2) 1.5 kg active ingredient ha^{-1}, and 3.0 kg ai ha^{-1}.
D. Frost severity (FS): 1) -2C, 2) -4C, and 3) -6C.
E. Number of frosts (FN): 1) One frost, 2) Three consecutive nights of frost, and 3) Five consecutive nights of frost.
F. Frost timing (FT): 1) Frost commencing the night before herbicide application, 2) Frost commencing the night after herbicide application, and 3) Frost commencing three nights after herbicide application.

In order to simulate the effects of those treatments on young establishing plants relative to mature established plants, the experiment was duplicated. Frost severity (FS) for the mature plants was changed to -2, -6 and -10C.

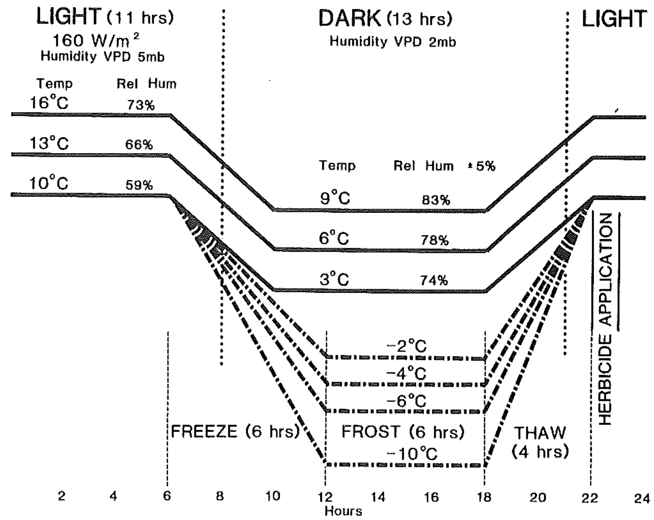

Figure 1. Summary of conditions in main controlled environment rooms (solid line) and frost room (dashed line).

Pre-treatment establishment

1. *Mature plants (spring sown).* One hundred 4.5 litre pots (filled with an Opiki loam) of each species were established by sowing pre-germinated seed on October 1979, and thinned to one plant per pot 6 weeks later. Plants were grown outside with watering as required. All plots were cut to 2 cm once in March 1980. In mid-June all pots were sprayed for insect pest and fungal disease, selected for uniformity, allocated to treatments and placed in the appropriate CE room on 30 June 1980. By this stage the plants occupied virtually the whole pot surface.

2. *Seedling plants (autumn sown).* In early March 1980 one hundred 3.3 litre pots of each species were established as for mature plants, but thinned to four plants per pot. These were raised in a temperature controlled glasshouse (25°C maximum, 15°C minimum). After 8 weeks, pots were selected for uniformity, allocated to treatments, and placed in the appropriate CE room on 5 May 1980.

Controlled Environment Rooms

Fig. 1 summarises the conditions and timing of operations of the three main CE rooms and the frost room. Initially pots were watered by hand, but in the later stage received two 50 ml applications per week of a modified Hoaglands A mineral nutrient solution (Hoagland and Arnon, 1938). Plants were acclimatized for 2 weeks before herbicide and frost treatments commenced. With only one frost room, frost treatments were coordinated to be completed over the following 2 weeks. Plants remained in the CE rooms for a further 4 weeks (5 weeks, mature plants).

Frost damage. The degree of frost damage was measured by the electro-conductivity method (Green and Warrington, 1978). Directly following frost treatment, 9 leaflets were randomly selected from each clover and lotus pot, or 1 cm leaf tips for cocksfoot, washed in distilled water plus a non-ionic detergent (Multifilm X-77, IWD), rinsed at least 5 times in distilled water, and incubated in 10 ml distilled water in capped glass tubes at 25C for 2 hours. After agitation the electrical conductivity of the solute plus leaf was measured (C_T). The sample tubes were then placed in containers of ethanol and stored at -18C for 12 hours to completely disrupt the leaves, thawed and re-incubated for 2 hours at 25C, and conductivity re-measured (C_K). The ratio C_T/C_K (conductivity ratio CR) indicates the degree of frost damage, leaves badly damaged by frost would have values close to 1.0.

Herbicide treatment. On the appropriate day all pots for spraying were removed from the CE rooms 1 hour after the beginning of the light period. Ethofumesate at the appropriate rates was applied using a small knapsack boom sprayer operating at 200 kPa and delivering 225 ha^{-1}. After drying, the pots were returned to the appropriate CE rooms.

Post-treatment procedures

On removal of the seedling experiment from the CE rooms on 30 June 1980, all pots were scored for growth (0-10 scale) and one representative plant removed from each pot for dry weight (DW). The pots were then stored outside until 3 September when they were scored for growth, and cut to 1 cm and yield measured. The mature plant experiment was removed from the CE rooms on 1 September 1980 and also scored for growth.

During September, all plants of both experiments were planted out as spaced plants (1 m) in a Kairanga silt loam, and grown on to seed harvest during February 1981. Plant size and flowering were scored on 26 January 1981, and at harvest plant fresh weight (FW) and seed yield for clover and lotus, and for seed-head numbers per plant for cocksfoot recorded. Lotus plants were harvested when 80% of pods were brown (ripe). Climate during this section of the experiments was near 'normal', with a slightly warmer early spring (+ 1C air minimum temperature for September and October 1980) and a warm, dry January (+ 1.4C air maximum, + 1C air minimum, with 16 mm rain (20% of 'normal')), which aided seed set and ripening.

RESULTS

Frost damage (Conductivity Ratio - CR)

Neither rate of herbicide (HR) nor its timing of application relative to frost treatment (FT) had any effect on the conductivity ratio in either experiment.

Plant age. Seedlings were more sensitive to frost than mature plants. At -2C there was no difference between seedling and mature plants, but at -6C seedlings suffered 65% more damage than mature plants (Fig. 2).

The interaction between number of frosts and frost severity (FS x FN $P<0.001$) indicated that the number of sequential frosts was only important at severe frost levels, additional frosts causing 40% more damage to seedlings compared to 25% for mature plants.

Plant species: Overall, lotus sustained twice as much frost damage as white clover irrespective of the number of frosts, whereas damage to cocksfoot increased 55% from 1 frost to 3 or 5 frosts (Sp x FN $P<0.001$, Table 1).

This variation in species sensitivity to frost was evident in a highly significant second order interaction with growth temperatures and frost severity for both seedling and mature plants (Sp x GT x FS, $P<0.001$, Fig. 3). Frost at -2C caused little damage. In general, damage increased with increasing frost severity and growth temperature, with lotus being more sensitive than white clover with cocksfoot intermediate. Acclimatization to lower temperatures (10/3C) generally increased frost tolerance, white clover in particular withstanding -10C of frost as mature plants. Heavy frosts on plants from warmer temperatures (16/9C) caused severe damage to all species.

Plant growth and herbicide effects

On removal from the CE rooms 4 weeks after frost and herbicide treatment, seedling plant dry weight reflected the degree of frost damage sustained (r = -0.38*), in that as growth temperature decreased and frost severity increased, seedling growth declined, with white clover being less effected than lotus, and cocksfoot intermediate. Being a relatively slow acting herbicide, ethofumesate had no effect on plant dry weight at this stage, but

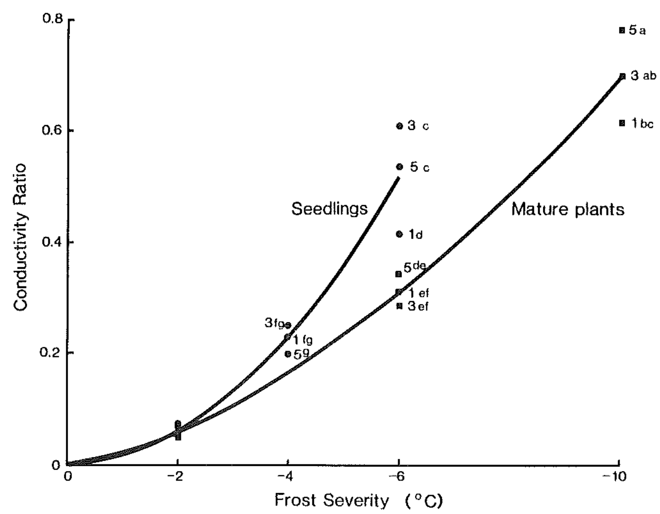

Figure 2. The differential effects of frost severity and frequency on seedlings compared to mature plants. ([•] seedlings [▪] mature plants accompanied by number of sequential frosts).

Table 1. The degree of damage, as indicated by the conductivity ratio, caused by sequential frosts on three species (meaned over frost level, seedlings and mature plants).

Species	Days of frost		
	1	3	5
Lotus	0.40 ab[1]	0.45 a	0.41 ab
W. clover	0.20 c	0.18 c	0.24 c
Cocksfoot	0.23 c	0.35 b	0.35 b

[1] values in each row followed by different letters are significantly different at $P<0.05$.

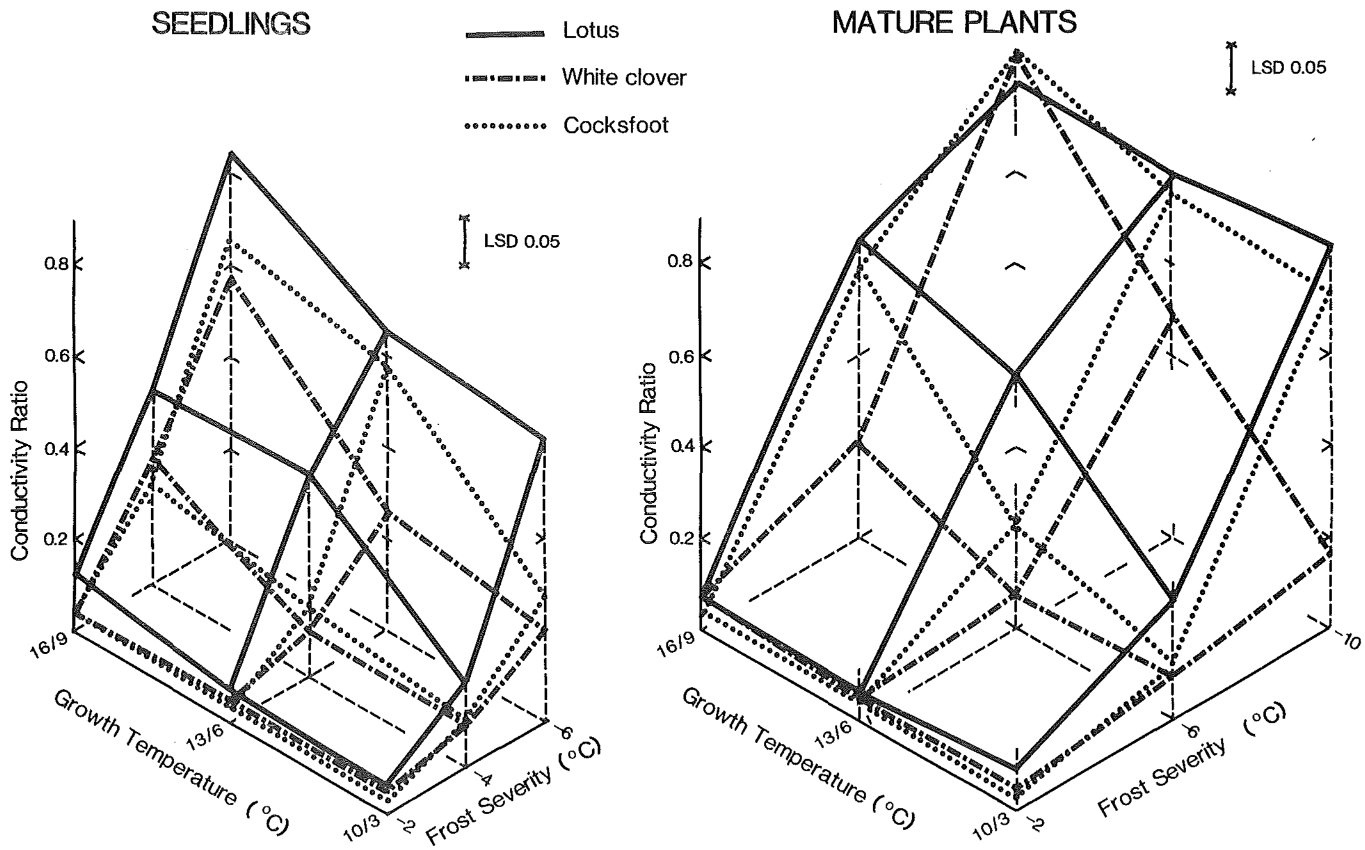

Figure 3. The interaction of growth temperature and frost severity on the degree of frost damage (conductivity ratio) or seedling and mature plants of lotus, white clover and cocksfoot.

visual symptoms were apparent (growth scores, Table 2) with the species by rate interaction (Table 2, P<0.01) showing cocksfoot to be unaffected, white clover strongly affected by increasing ethofumesate, with lotus affected at the high rate only.

After a further seven weeks of growth outside, the effects of growth temperature in the CE rooms had diminished and been replaced by the strongly developing herbicidal effects interacting with species and frost severity as shown by yield per pot (Sp x FS x HR P<0.001, Fig. 4) and to a lesser extent growth scores (P<0.05, not presented). Ethofumesate severely stunted all growth of white clover at both rates such that no herbage was present above the 1 cm cutting level at harvest on 3 September 1980. Plants were not killed, still rating a 20% growth score at that time (Table 2). Cocksfoot was least affected by ethofumesate with only a minor reduction under the highest frost x herbicide treatment. Lotus showed increasing damage with increasing frost and herbicide rate, but was considerably more tolerant of ethofumesate than white clover.

Mature plants on removal from the CE rooms showed a similar pattern to the seedling plants, growth scores showing the reverse pattern (r = -0.45*) of frost damage exhibited. Similarly, the herbicidal effects were still developing (Table 2) at this point, with white clover exhibiting similar tolerance to ethofumesate as lotus, in contrast to being treated as seedlings. No subsequent measurements were made to see if this developed to interact with frost severity as occurred in the seedling experiment.

Recovery growth and seed production

There was no loss of plants following planting out and by January 1981 all lotus plants had fully recovered from the effects of ethofumesate, flowering, size of plant (FW) and seed yield being similar for all treatments. Cocksfoot was also unaffected by treatment (Table 3).

At planting, white clover was suffering severely from ethofumesate, and although all plants recovered and grew well, those that had received ethofumesate at 3 kg ha^{-1} were still considerably smaller than untreated plants, particularly those treated as seedlings. The effects of ethofumesate on flowering and seed production was even greater, being severely suppressed by both rates of ethofumesate.

Table 2. The development of ethofumesate herbicide effects on seedling and mature plants, growth scores (0 = dead, 10 unaffected) expressed relative to the zero application = 100 (actual values mg plant^{-1} in parenthesis are for total shoot DW as seedlings, and as harvested herbage DW for mature plants).

Plant age (weeks since treated)		Ethofumesate (kg ai ha^{-1})			
Species	0	1.5		3.0	
Seedlings (6 weeks)					
Lotus	(7.11)	65	b[1]	59	c
W. Clover	(7.81)	48	d	38	e
Cocksfoot	(8.07)	96	a	99	a
(13 weeks)					
Lotus	(7.48)	73	b	60	c
W. Clover	(7.26)	27	d	22	d
Cocksfoot	(7.57)	97	a	97	a
Mature (5 weeks)					
Lotus	(4.81)	72	b	71	b
W. Clover	(5.48)	74	b	69	b
Cocksfoot	(7.37)	98	a	99	a

[1]Values in each row followed by different letters are significantly different at $P<0.05$.

DISCUSSION

The development of frost hardiness in plants is dependent on pre-conditioning by prolonged exposure to a combination of short daylength (≤11 hrs) and low night temperatures (<5C) (Greer and Warrington, 1982). The more severe frost damage sustained by seedlings compared to mature plants (Fig. 2), could have been due in part to differences in their development of frost hardiness, as well as plant age. Seedlings had only 2 weeks conditioning in the growth cabinets between establishment in a heated glasshouse and frost treatment, whereas the mature plants were held outside until mid-winter before placement in the cabinets and would have developed greater frost hardiness. Nevertheless, the pattern of interaction between frost severity and growth temperature on frost damage was similar for both seedlings and mature plants (Fig. 3). Only the 10/3C treatment provided any conditions for increasing frost hardiness and then only to moderate frosts for lotus (-4 to -6C), although there is some evidence of frost hardiness for white clover and cocksfoot at medium frost severity in the 13/6C treatment. The high degree of frost damage to lotus herbage grown at the higher temperatures parallels the experience of farmers that have lost large amounts of lotus herbage produced in summer or early autumn, to early frosts, particularly in the cooler South Island high country.

O'Connor et al., (1975) showed that the effectiveness of ethofumesate increased progressively from the warmer northern winter to the cooler southern regions. It has been shown that ethofumesate is most effective when applied so that its period of maximum activity coincides with the coldest part of the winter (June-July) (Allen et al., 1974), when plant growth rates are lowest, and microbial degradation of the ethofumesate slowest (Hoogstraten et al., 1974, Rahman et al., 1978). The growth temperatures used were designed to cover the range of winter temperatures encountered in New Zealand and therefore could have been expected to have an effect on ethofumesate activity. This did not occur. The only lasting interaction of treatments with ethofumesate was the severity of the frost on subsequent growth (Fig. 4). This would suggest that frost events may play the dominant role in determining the effect of winter severity on plant growth, rather than the general temperature regime.

Neither the number of sequential frosts or their timing in relation to ethofumesate application had any effect on subsequent herbicidal activity. Entry of ethofumesate into herbage damaged by frost before application could have increased herbicidal activity. This did not occur, possibly because the tissues were damaged to a degree that transportation of any herbicide absorbed was not possible, and also that foliar absorbed ethofumesate is not as effective as that absorbed through the roots (Harley, 1975). This could explain why even with considerable frost damage to herbage, cocksfoot sensitivity to ethofumesate was not increased significantly.

Of the three species tested, cocksfoot would be classed as tolerant, lotus as moderately tolerant, and white clover as sensitive to ethofumesate. Sensitivity of plant species to ethofumesate appears to depend on the degree of translocation within the plant and the rate at which it is metabolized. Tolerant species have low translocation, particularly of foliar applied ethofumesate, and high metabolism of ethofumesate, and susceptible species the converse (Duncan et al., 1981, 1982). Translocation is greater from root absorbed ethofumesate and is concentrated in the shoot meristem, inhibiting mitosis, deforming the growing point (Fisons Ltd., 1973) and stunting growth. As older leaves die the plant is reduced to a tight cluster of deformed reduced stems, particularly in white clover. On its own, ethofumesate does

Table 3. The effect of mid-winter application of ethofumesate to seedling and mature plants on their subsequent relative plant size and seed yield.

Rate Species	Seedlings 0		1.5		3.0		Mature plants 0.		1.5		3.0	
26 January 1981												
Plant size:												
Lotus	100	a[1]	100	a	100	a	100	a	101	a	101	a
W. clover	100	a	87	ab	58	b	100	a	95	a	64	b
Cocksfoot	100	a	102	a	99	a	100	a	97	a	102	a
Flowering:												
Lotus	100	a	100	a	100	a	100	a	101	a	99	a
W. clover	100	a	29	b	12	c	100	a	33	b	25	b
Cocksfoot	100	a	103	a	110	a	100	a	98	a	100	a
At Harvest												
Fresh weight (per plant):												
Lotus	100	a	113	a	104	a	100	a	98	a	104	a
W. clover	100	a	76	b	37	c	100	a	87	ab	66	b
Seed weight (per plant):												
Lotus[2]	100	a	79	a	72	a	103	a	111	a	95	a
W. clover[2]	100	a	11	b	6	b	100	a	39	b	9	b
Cocksfoot[3]	100	a	104	a	106	a	100	a	93	a	107	a

[1]Values in each row followed by different letters are significantly different at $P < 0.05$.
[2]Seed weight per plant. [3]Seed heads per plant.

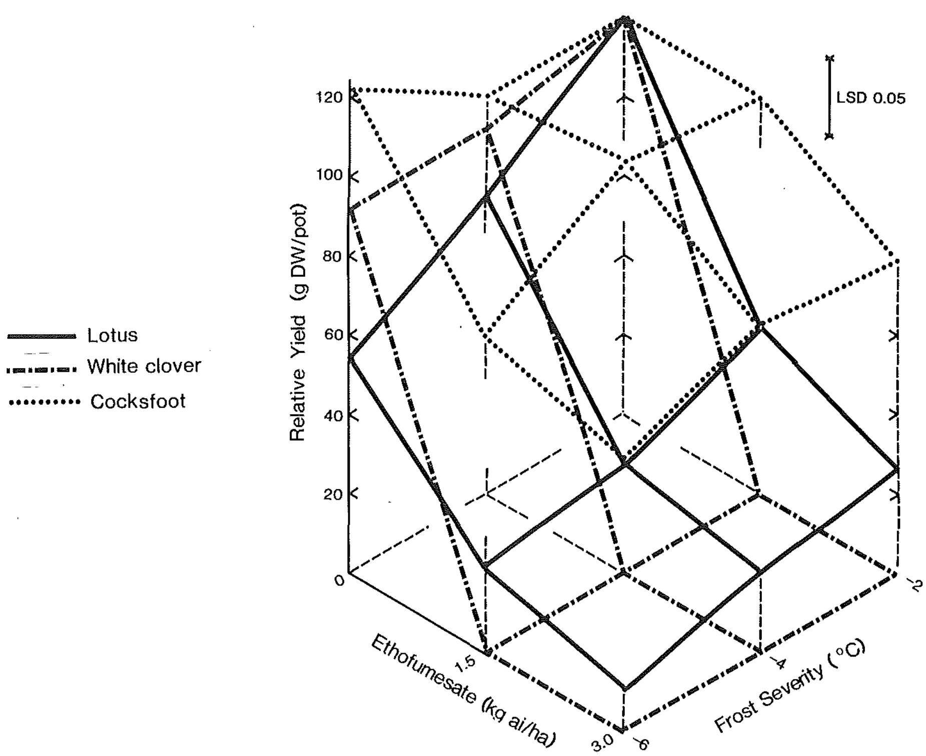

Figure 4. The relative effects of frost severity and ethofumesate on the dry weight of lotus, white clover and cocksfoot, 13 weeks after treatment as seedlings.

not kill white clover and the plant remains in a stunted condition until herbicidal activity ceases. This active period may last several weeks depending on soil temperature and microbial degradation of the ethofumesate in the soil. Subsequent new growth is normal in appearance and growth rate. It is during this period when the plant is moribund that 'control' of white clover is effected by competition for light and space by the more tolerant species lotus smothering out the weakened sensitive species white clover. Brock and Henderson (1980) found that ethofumesate at 2 kg ha^{-1} in winter would eliminate white clover from lotus in this way. However, because lotus is moderately susceptible to ethofumesate, the interaction between rate of application and environmental conditions becomes critical. Enhancement of herbicidal activity by frost, may well transform the effects of what would normally be a moderate rate of ethofumesate into a heavy rate. If indeed the main factor enhancing herbicidal activity is reduced growth per se, then timing of frost in relation to application may not be critical, and could have equal effects if the frosts occurred later (3-4 weeks) provided the herbicide was still active. When planning applications of ethofumesate, some knowledge of the likely severity of winter conditions for 6-8 weeks after application needs to be taken into account.

Despite the apparent severe effects of winter applications of ethofumesate, lotus fully recovered by summer and seed yields were unaffected. Even though white clover recovered from ethofumesate treatment in the absence of competition, it never recovered in size or vigor to the level of untreated plants by seed harvest time (Table 3). Flowering and seeding in particular were still greatly reduced. It would appear that most of the floral primordia initiated in response to cool winter temperatures (vernalization) (Thomas, 1980), were rendered ineffective by the ethofumesate applied in winter. A second, though much reduced flowering initiated in response to higher temperatures in summer (Thomas, 1980), which was compounded by the smaller size of the treated plants, resulted in only small quantities of seed being produced. Since some white clover often survives in weaker areas of the lotus stands, or regenerates later from buried seed (Hyde and Suckling, 1953; Lancashire et al., 1985), annual winter treatments of ethofumesate will be necessary in lotus seed crops.

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Competition Between Vegetative and Reproductive Growth and its Effects on Reproductive Abortion and Pod Set in Soybean (*Glycine max* (L.) Merrill)

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ABSTRACT

Reproductive abortion is a major limitation to yield in soybean. Abortion levels in field plantings in New Zealand were over 80% for the cultivar Amsoy. The mechanisms responsible for this are unclear, but it has been suggested that abortion is either under direct hormone control or the result of intraplant competition for nutrients. The effects of intraplant competition between vegetative and reproductive growth in glasshouse-grown soybeans were studied by removing 50 or 100% of all young leaves starting from three different stages of reproductive development. Two related cultivars were used; the indeterminate Amsoy and the semi-determinate cultivar, Matara.

In both cultivars, young leaf removal (YLR) diverted assimilates to cause an increase in flowers or pods for at least a short period during development. Matara has a less plastic growth response than Amsoy and did not respond well to treatment. However, in Amsoy, 50% YLR starting at growth stage R3 (Fehr and Caviness' scale) increased both flower and pod numbers per plant by 44%, the increase in pod set being mainly concentrated on the middle part of the main stem. YLR did not change the proportion of combined reproductive abortion in either variety (79% in Matara, 82% in Amsoy). Losses of reproductive units occurred at all stages during development, but most dramatically during the flowering stage. The results obtained have been fitted into a model constructed to describe nutrient flows into reproductive components. This approach confirms that these data cannot be fully explained on the basis of assimilate partitioning alone.

Additional index words: Leaf removal

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INTRODUCTION

Reproductive abortion is an important factor to be considered in yield improvement in soybean (*Glycine max* (L.) Merrill) and other legume crops. Reproductive abortion in soybeans has been reported to vary from 32 to 83% of yield potential (Van Schaik and Probst, 1958a; 1958b). At present, the mechanisms responsible for high reproductive abortion are unclear. A number of hypotheses have been proposed to explain this effect, i.e. nutrient deficiencies (Wiebold et al., 1981), hormonal control (Huff and Dybing, 1980) and vascular constrictions (Gates et al., 1983).

Weibold et al. (1981) have suggested that under normal conditions, a localized decrease in photosynthesis can cause an increase in abortion in adjacent reproductive units because of a reduction in available carbohydrate. Antos and Wiebold (1984) showed that high abortion rates in the lower one-third of the canopy were associated with low concentrations of total soluble sugar and starch in the stem and petioles. However, Heitholt et al. (1986) reported that concentrations of carbohydrates did not change in fully open flowers even though the percentages of reproductive abortion were altered by source-sink manipulations. Moreover, reproductive abortion occurred mainly at the flowering stage when photosynthetic rate was relatively high, and during the first days after flower opening. Flowers are small sinks relative to the size of the whole plant as indicated by a slow absolute dry matter accumulation rate (<5 mg $flower^{-1}$ day^{-1}) (Heitholt, et al., 1986). Therefore, it seems that while flower abortion may not be limited by the available supply of photoassimilate present during flower growth, the hormonally controlled maintenance of sink strength of flowers may be crucially important.